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THE JOURNAL OF THE SOCIETY OF AUTOMOTIVE ENGINEERS

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Coming Meetings of the Society

THE spirit of cooperation so greatly fostered by the war taught all of us the value of collective reasoning. We learned to our mutual advantage that the other fellow's way of accomplishing a production or engineering result oftentimes excelled our own. The end of the war fortunately did not mark the end of the appreciation of this fact, nor the complete cessation of the trading of experience between men of influence in the automotive industry, but the disbanding of ordnance, aviation and similar Government boards and committees has limited the opportunity for contact between men in the same industrial work.

One paramount agency remains to foster the practice of collective reasoning for the advancement of automotive engineering and its related industrial sciences. That agency is the Society of Automotive Engineers. The technical meetings of the Society provide the opportunity for the exchange of practice and experience so vital to all of us during these troublous times of reconstruction and economic readjustment. The papers presented at our meetings serve primarily to introduce a topic for discussion. It is the verbal exchange of opinion, the submission of constructive criticism and the contribution of individual experience, following the presentation of the papers, which excite the greatest interest among our membership. Personalities are an important phase of this discussion which cannot be incorporated in the record of the meeting as published in THE JOURNAL. It is the personal contact with the other members of our profession which fosters frank expression. Members of the Society who have actively participated in the meetings and discussions in the past have learned to appreciate that this personal contact with its attendant exchange of thought accomplishes in a few days a comprehensive understanding of important automotive engineering problems which other agencies cannot reach in a narrow way in months. Performance of this valuable service in the past particularly emphasizes the importance and value of the coming winter meetings of the Society which find us in the midst of a period of readjustment and doubt wherein the engineer must accept a major responsibility for the future stabilizing of the industry.

Annual Meeting

The Annual Meeting of the Society occurs during the week of the New York Automobile Show as in the past, the dates being Jan. 11 to 13. The program of professional sessions which has been arranged to cover those subjects considered of greatest vital interest at this time follows:

TUESDAY, JAN. 11

Morning and Afternoon—Standards Committee Meeting

WEDNESDAY, JAN. 12

Morning—Business Session
Discussion—The Engineer's Place in Industry
Afternoon—Body Engineering Session
Aeronautic Session

THURSDAY, JAN. 13

Morning—Fuel Research Session
Afternoon—Fuel Research Session
Highways Session
Chassis Design for Fuel Economy Session

After the business session on Wednesday morning there will be a discussion of the part the automotive engineer must play in the industry. The Body Engineering and Aeronautic Sessions will be conducted simultaneously in the afternoon, this innovation in the meetings of the Society coming as the natural result of the increased activity and broader scope of the organization. The body engineers are showing intense interest in their session and it is probable that it will become an annual affair recognized as the style forum of their profession. The program for the Aeronautic Session is complete and will accentuate the development of commercial aviation along both lighter and heavier-than-air lines. The developments in airplane design during the past year will be outlined. Vice-President Glenn Martin will preside at the Aeronautic Session.

The Fuel Research Session, with President J. G. Vincent presiding, will occupy both Thursday morning and afternoon. The interest in this subject is so general and the development so great that one session will hardly enable the proper consideration to be given it. Past-President C. F. Kettering, whose experiments in fuel chemistry and physics of combustion have been watched with interest during the summer, will present his conclusions before the morning session, his talk, with the discussion, requiring that entire meeting. In the afternoon Dr. H. C. Dickinson of the Bureau of Standards and others will cover various phases of the fuel topic. The Chassis Design for Fuel Economy Session plans are as yet incomplete. H. M. Crane will act as chairman of

this session which is expected to encourage more concentrated study of the reduction of power loss and waste beyond the engine. Past-President Herbert W. Alden will preside at the Highway Session, which will be devoted to the consideration of better highway construction for permanency and the best plan of cooperation in this work for the automotive engineer to follow.

The Annual Dinner at the Hotel Astor, Thursday, Jan. 13, will maintain the prestige set in previous years filling the large ballroom to capacity. The Carnival announcement will soon reach the members but will disclose little of the character of this year's affair, which H. G. McComb, chairman of the committee, wishes to conceal. Wednesday evening, Jan. 12, is Carnival Night in the Astor ballroom, which will be especially prepared for the occasion. Application blanks for both the Dinner and Carnival tickets have been mailed, and members are urged to give these immediate attention.

Motor Boat Meeting

The Motor Boat Meeting, the first meeting of the winter, will be held at the Automobile Club of America, New York City, Tuesday evening, Dec. 14. The national Motor Boat Show will be in progress during this week at the Grand Central Palace, and automotive engineers interested in motor boats will have an opportunity to inspect the more recent developments in that field. The Metropolitan and Philadelphia Sections are joining with the Society in the preparations for the Motor Boat Meeting, the former having arranged an inspection trip through a boat and engine factory in the vicinity of New York City on Tuesday afternoon. This inspection tour will constitute the December meeting of the Metropolitan Section.

The Motor Boat Dinner will be informal in character and Vice-President C. A. Criqui, representing the motor boat membership of the Society, will preside. Mr. Garfield Wood and William B. Rogers, Jr., will be the dinner guests, the latter giving a short talk on the Standardized Boat and the Motor Boat Industry. The program for the technical session which follows the dinner will be devoted to both the pleasure and commercial types of motor boat and the heavy-oil and gasoline engines. It is planned to encourage an open discussion of the probable developments upon which the motor boat engineer must concentrate during the coming year.

The National Association of Engine and Boat Manufacturers has arranged a very large and representative motor boat dinner on Thursday of the same week. The American Power Boat Association is combining with it, and our members are also urged to attend. This meeting of the builder with the motor boat owner, which is a new venture, deserves commendation and support, for it is certain to accomplish a better understanding of each group's problems by the other. Reservations for both of these dinners can be made by mailing a check to the Society office. The tickets for the S. A. E. dinner are $3 each.

Columbus Tractor Meeting

The interest of the members in the technical sessions to be held during the week of the National Tractor Show at Columbus, Ohio, has resulted in arrangements being made by the Meetings Committee to hold a morning and afternoon tractor meeting on Thursday, Feb. 10. Programs for these two meetings are now being arranged and the tractor engineers are urged to submit suggested topics and authors for consideration by the committee. The annual Tractor Dinner will be given at the Hotel Deshler on Thursday evening following the professional sessions.

The members' attention is again called to the probability of serious hotel congestion during the automotive shows in the cities where the winter meetings are to be held. This applies particularly to Columbus, and the filing of reservations with the hotels should receive prompt attention.

Chicago Meeting

Plans are about complete for the Chicago Meeting. There will be morning and afternoon technical sessions on Wednesday, Feb. 2, which is during the Chicago Automobile Show week. The annual Chicago dinner will be held at the Hotel Morrison on the evening of the same day.

AVIATION PARACHUTE

THE parachute used by aviators is folded snugly inside a pack carried on the back. The operator steps off, allows himself a couple of seconds to fall clear of the machine, then pulls a wire depending over his shoulder. This wire opens the spring doors of the pack and releases a small pilot chute about 2 ft. in diameter. The pilot springs open automatically and catching the rush of air, draws the main chute from the pack. In the top of the main chute is an automatic vent which, opening to a width of 5 ft. when the big parasol first unfolds, gives the air compressed within a chance to escape and lessens the danger of blowing the chute apart. When the fall has been checked rubber springs or shock-absorbers in the vent close it in until but a small hole remains. At the atmospheric pressure wherein most parachute drops from ordinary altitudes are made the speed attained by the operator in 2 sec. fall is sufficient to create enough pressure under the pilot chute to cause it when released to yank the big one at once from its pack. Usually the operator is descending at normal speed after falling less than 200 ft. However at great altitudes the atmosphere has not sufficient effect on the pilot chute until the operator has fallen a great distance and attained a terrific speed. The shock when the parachute does open is severe with a chance of the silk flying into ribbons.—Air Service News Letter.

AUGUST GASOLINE PRODUCTION

THE production of gasoline in August was the highest since December, 1917, according to statistics compiled by H. F. Mason, petroleum economist of the Bureau of Mines. The daily average for the month was 14,327,143 gal. Stocks of gasoline at the refineries on Aug. 31 amounted to 18 days' supply compared with 33 and 23 days in 1919 and 1918.

The number of refineries that operated in August was 322, an increase of 11 over July. The average daily capacity of the refineries in operation in August was 1,671,495 bbl. of crude oil compared with a daily capacity for July of 1,637,145 bbl. For August, 1919, the daily capacity of the 287 plants in operation was 1,276,765 bbl.

The Combustion of Fuels in the Internal-Combustion Engine

By Thomas Midgley, Jr.[1]

Mid-West Section Paper *Illustrated with* Photographs and Diagrams

For several years past our laboratory has been conducting a research into the behavior of various fuels during combustion. This is merely one phase of the fuel problem. We consider it a fairly important phase and have spent some time in trying to find out what happens inside the cylinder of an engine during and following the combustion period. I will review briefly some of the salient points in the fuel problem proper, which has more of an economic than an engineering nature, although engineering must be applied in its solution. This is the age of applied power. Mankind has learned within the last 100 years how to apply natural forces that, as history shows us, previous generations did not utilize. At present 75 per cent of this power is applied by the internal-combustion engine. This is a glowing tribute to the genius of the automotive engineer.

Power from the internal-combustion engine depends upon a supply of liquid fuel. The situation is that there are some 7,000,000 or 8,000,000 automobiles in use in the United States, and each requires about 600 gal. of gasoline annually. The total is something like 5,000,000,000 gal. The oil industry must exert every possible effort to supply 4,500,000,000 gal. this year. This is why there is a fuel problem. Oil men tell us that, as automotive engineers, we ought to design efficient engines which will deliver twice as many miles per gallon. They say that this would be equivalent to doubling the supply of fuel. They go further and tell us how we ought to build these cars. They say we ought to adopt European practice, gear accordingly and change gears every time we come to a 5 per cent grade. This is a good theory, but will the oil men sell such cars if we build them? I do not believe the American public would buy such a car. The true solution of this problem is to deliver to customers not only what they must have but also what they want.

This result could be accomplished if we could raise compressions, but we cannot raise compressions successfully merely by reducing the clearance volume because, at about 100 to 110 lb. per sq. in., which is really low compared to what we ought to have, the engines pound every time they are accelerated and are unpleasant to drive. The incipient knocks such as the general public complains of to-day are not really harmful, but the heavier knocks caused by running at compressions of 125 to 130 lb. per sq. in. on automobile gasoline are harmful. We have data showing that, during an hour's run on an engine under such conditions, several of the piston-heads were cracked and every spark-plug practically ruined. Therefore, the problem confronting the research engineer is not only to determine what the knock is, but also how to overcome it. I will tell of the work we have done toward overcoming the knock, explaining the latest theories concerning what it is and prefacing this with a review of some of the simpler relations of organic chemistry.

Chemistry of Fuels

The engineer expresses physical relationships, such as the power output of an engine, by curves. Such curves, however, serve only as a graphical representation of relationships. The chemist uses structural formulas to represent graphically certain relationships which exist within the molecule of a substance. By these structural formulas it is possible to foretell to a certain extent the properties that a given material has; so, by examining the structural formula of a fuel that may never have been run in an internal-combustion engine, we can predict, without actually trying the substance, what compression pressures it will withstand and how it will behave during combustion.

In these structural formulas, if we have an atom of carbon represented by C and wish to combine it with hydrogen, which has the symbol H, we represent this combination structurally as C-H. The line between the C and the H is called a bond, and is like a rubber band holding these two things together. If these two letters were pulled apart, the rubber band would finally break. In thus stretching the rubber band, energy would be used in breaking it; so, the band in that sense represents a certain amount of energy that is holding the carbon and hydrogen together.

All liquid fuels have carbon and hydrogen for their basic heat-giving components. The simplest compound we can have between carbon and hydrogen is represented by a structural formula in Fig. 1 on page 491, showing carbon with four bonds and a hydrogen atom attached to each bond. This is called methane, and is the principal constituent of natural gas. If one of the hydrogen atoms is removed and another carbon atom and three more hydrogen atoms are attached we have ethane, which is another gas. This process can be continued indefinitely, as shown also for hexane in Fig. 1 on page 491. Compounds have been isolated which have as many as 50 of these carbon atoms fastened together in a long row. They are called "chain compounds" because the carbon atoms are arranged like the links of a chain.

The average of present-day gasoline has about nine of these carbon atoms. If it had only five or six we would be satisfied with the quality of the gasoline we buy. The substances which has just been described belong to what is called the paraffin series of hydrocarbons. When compounds having 10 or more carbon atoms are put through a cracking furnace, the bonds are stretched and one or more soon break. Cracking expresses the thing that happens; the compound is cracked into parts. We then have double molecular bonds.

Suppose we take a compound such as C-C-C and its proper number of H symbols, remove two of the hydrogen atoms and put two bonds between two of the carbon

[1] M.S.A.E.—Chief Engineer, fuel section, General Motors Research Corporation, Dayton, Ohio.

atoms, as for propane and propylene. (See Fig. 1). The resulting substance would be called an unsaturated compound and is known as an olefin. When one of the paraffin molecules is broken in two, two hydrogen atoms are lacking from the number necessary to completely satisfy or saturate the bonds of the carbon. So there is formed some unsaturated substance containing double bonds and called an olefin. These are the principal things we have to deal with in cracked gasoline.

Another type of compound, having a different structure, is known as benzol. The structure of benzol, which is shown diagrammatically in Fig. 1, is what we are forced to consider it in these thermal relations, and may not be the true structure from the chemical standpoint. It is called a ring compound because the carbon atoms are in a circle and held together very tightly. It has a hydrogen atom attached to each one of its carbon atoms, and each atom of carbon has four bonds. Benzol can be hydrogenated by passing it through a furnace charged with a nickel catalyst, in the presence of hydrogen. By this process the middle bonds are wiped out and the number of hydrogen atoms in the molecule is doubled, thus making cyclohexane from the benzol, the change being shown in Fig. 1. This type of compound is found in California gasoline. In fact, some members of this series are found in all the gasolines of the world except those of Pennsylvania. They constitute much better engine fuel than the paraffin series. We ran a Liberty engine on cyclohexane with 200 lb. per sq. in. compression pressure. There was no knock, because this compound naturally does not knock.

The alcohols form another class of compound having the chain structure in part. There is a complete series of these. From the diagram, Fig. 1, it can be seen that the molecular structure of this type of compound differs from that of the paraffin molecule by having one H replaced by OH, oxygen and hydrogen. This OH group is characteristic of the alcohols. The compound of which the structure is shown in Fig. 1 is ethyl or grain alcohol. This substance boils at about 78 deg. cent. (172 deg. fahr.). The alcohols will withstand a very high compression without knocking, and give a burn entirely free from carbon.

The ethers form a class of substance also composed of carbon, hydrogen and oxygen. Although dimethyl ether, the structure of which is shown in Fig. 1, has exactly the same carbon, hydrogen, oxygen ratio as has ethyl alcohol, the structure is actually very different. The ethers boil at a much lower temperature than the alcohols of equal molecular size. The effect of the difference in structure between these two classes of substances becomes very manifest when ether is run in an engine. The ethers are violent knockers, and it is hardly possible to get compression pressures sufficiently low to prevent them from knocking. We believe that the difference between the behavior of the alcohols and the ethers is due to the fact that in the alcohols the oxygen is already attached to a hydrogen atom, while in the ethers the oxygen is attached to two carbon atoms and has no immediate access to a hydrogen atom.

I have here a few fuels and will show the difference between cyclohexane and benzol, just as they burn. I cannot make any of them "knock" during this illustrative test, but I can show how a little difference in structure between two fuels makes a big difference in the way they burn. The benzol molecule is represented by C_6H_6, six carbon and six hydrogen atoms and the cyclohexane molecule contains six carbon and 12 hydrogen atoms, as shown in Fig. 1. If a small quantity of benzol is put into one watch-glass and some cyclohexane into another and lighted, the benzol flame shows unmistakably that it contains the greater percentage of carbon. Cyclohexane contains twice as much hydrogen as does benzol. These formulas really mean something, after all.

Another example is carbon bisulphid, a compound of carbon and sulphur, with double bonds as shown in Fig. 1. This has a very low auto-ignition point; that is, it will light at a temperature of 140 deg. cent. (284 deg. fahr.) in air. For comparison with the carbon bisulphid, I will take a little ordinary gasoline, heat a wire fairly hot and put it in the gasoline. Nothing happens. I will now heat it again and touch it to the carbon bisulphid. It lights from contact with a wire that is barely warm, which shows the difference in the auto-ignition points of the two substances. When carbon bisulphid is run in an engine it shows a tremendous amount of auto-ignition, but it will not make an engine knock, and disproves the idea that knocking is auto or self-ignition, or preignition in the true sense.

The difference in volatility between gasoline and kerosene can be shown readily by pouring a little gasoline into one watch-glass and some kerosene into another and trying to light each with a match. Their ignition temperatures are almost identical. I believe it has been determined that kerosene is 20 to 30 deg. lower than gasoline, but this has nothing to do with the fact that kerosene cannot be lighted with a match. There is not enough vapor above the kerosene to ignite; the match flame simply goes out. Of course, the gasoline can be lighted because of the vapor arising from it, which makes it easy to start.

To show the difference in the flames of alcohol and gasoline, we will compare them in the same manner. The alcohol flame is blue. The yellow in the gasoline flame is incandescent carbon. During combustion the oxygen prefers burning the hydrogen to burning the carbon. In burning gasoline in this way the structure is such that the oxygen can readily get at hydrogen enough to satisfy it, and there is not enough oxygen present to burn the carbon completely. In the case of alcohol, an insufficient amount of hydrogen is liberated when the alcohol is broken up to satisfy all the oxygen that can get at it from the air. The result is that the excess oxygen combines with the carbon and the carbon is not left to become incandescent as it is in the case of gasoline.

Such demonstrations are simply to show how these different fuels behave when they are burned in air. They have no particular relationship to the manner in which the same fuel burns when it is first made into a semi-gas and then exploded or ignited from a spark-plug in an engine cylinder while under compression. In this case the results are much different from those when the fuel is spread out and allowed to boil and burn as it chooses. But the tests we have made show the effect of this difference in structure on the behavior of fuels. One should keep clearly in mind that we can very nearly tell by the structure of a fuel what it will do.

Gas-Engine Indicator

When we began studying how the different fuels behave inside of the gas engine several years ago, we decided that one of the first things we had to have was an indicator that we could rely upon and use continuously to study the behavior of fuels inside of the cylinder.

Fig. 2 shows a cross-section of the indicator as finally developed. The position of the pressure element is shown at the bottom. A beam of light from an automobile headlamp bulb, shown at the right, strikes a concave

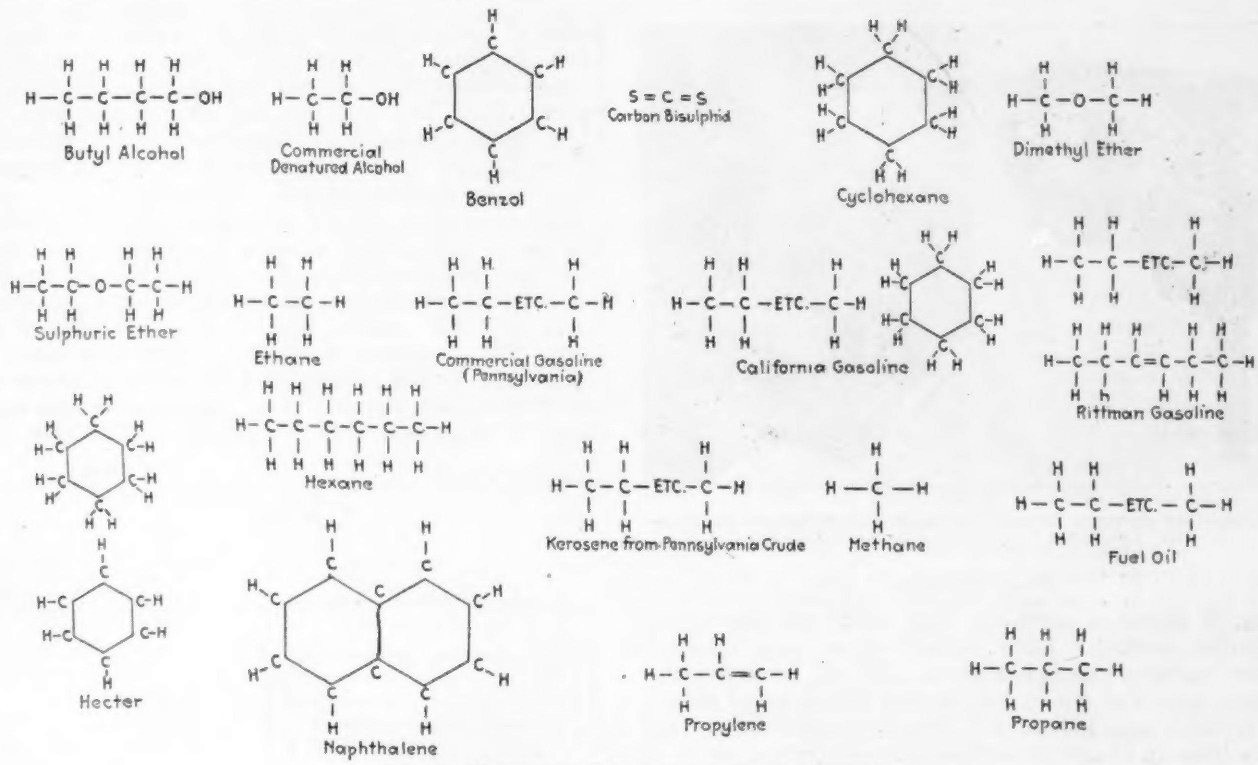


FIG. 1—MOLECULAR STRUCTURE OF VARIOUS FUELS

mirror on the top of the pressure element at the left and is returned to an octagonal mirror adapted to be rotated by a synchronized electric motor. The beam is then reflected from the face of this mirror to the glass front of the box, on which it traces an optical card indicating the conditions within the cylinder. Fig. 3 shows the pressure element of the indicator, which is of the piston type. The function of the pressure element is to swing the pivoted mirror to such positions that, at all times, its vertical angle is proportional to the pressure in the combustion-chamber of the engine. One end of the pressure element screws directly into the combustion-chamber of the engine. Pressure in the cylinder operates against the piston to compress the resisting spring. This movement is transmitted through a very light rod to an arm which operates to change the vertical angle of the pivoted mirror in proportion to the pressure on the piston. The point of light moves up and down with a corresponding change in the angle of the pressure-element mirror. At the same time it moves horizontally with the rotation of the octagonal mirror, thus tracing an indicator card on the curved glass. Fig. 4 shows the rise on compression, the burn, which is accompanied by a knock, and the return.

Fig. 5 shows the method of taking photographs of indicator cards on an engine. The indicator is in place on the engine and a piece of sensitized paper is being held in front of it. A timing device on the small table at the right allows a high voltage to be applied to the lamp for just one revolution of the engine. This high voltage increases the actinic light and an image of the indicator card is recorded on the paper.

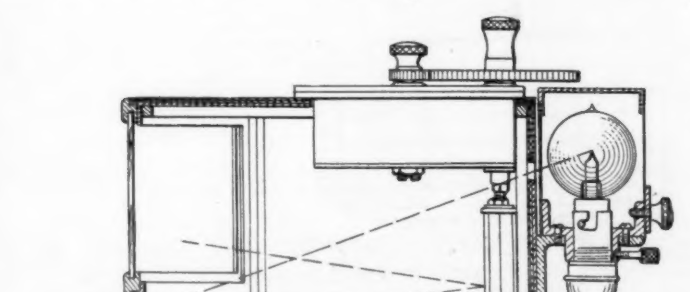


FIG. 2—CROSS-SECTION OF A RECENTLY DEVELOPED OPTICAL GAS-ENGINE INDICATOR

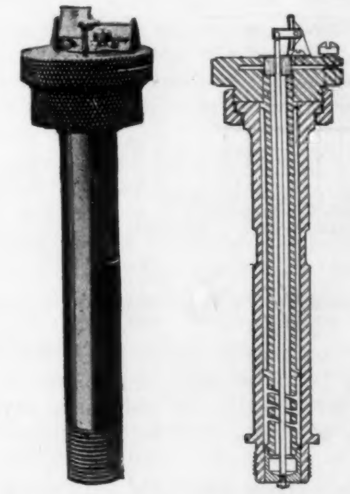
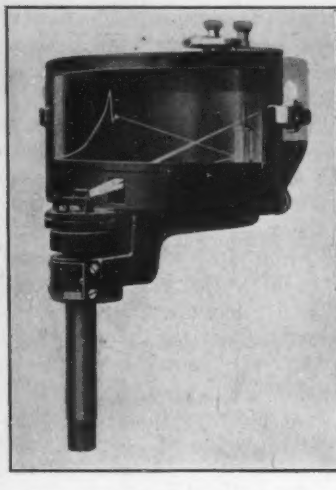


FIG. 3—PRESSURE ELEMENT OF THE INDICATOR



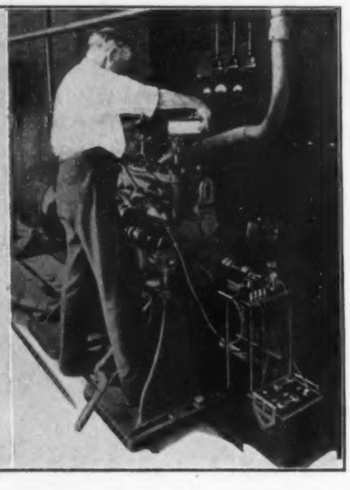


FIG. 4—THE OPTICAL SYSTEM OF THE INDICATOR FIG. 5—PHOTOGRAPHING GAS-ENGINE INDICATOR CARDS

FUEL STUDIES

Fig. 6 shows a complete fuel study of commercial denatured alcohol. Both pressure-time and pressure-volume indicator cards are given. On the pressure-time card the points at which the various events occur within the cylinder are indicated. The pressure-volume card means little in the study of fuel characteristics, but it is given here along with the pressure-time card. The distillation curve of the fuel, as determined by the standard method given by the Bureau of Mines, is shown also.

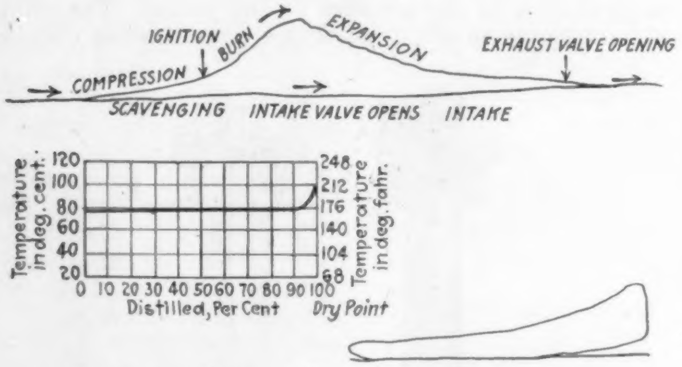


FIG. 6—FUEL STUDY OF COMMERCIAL DENATURED ALCOHOL

From a study such as is given here, the characteristics of a fuel can be obtained and considered, and, on the basis of the information so obtained, a prediction can be made as to what the fuel will do under any other set of conditions.

Fig. 7 shows carbon bisulphid producing genuine preignition. The pressure-volume card shows how early ignition comes and that it gives a negative loop. The

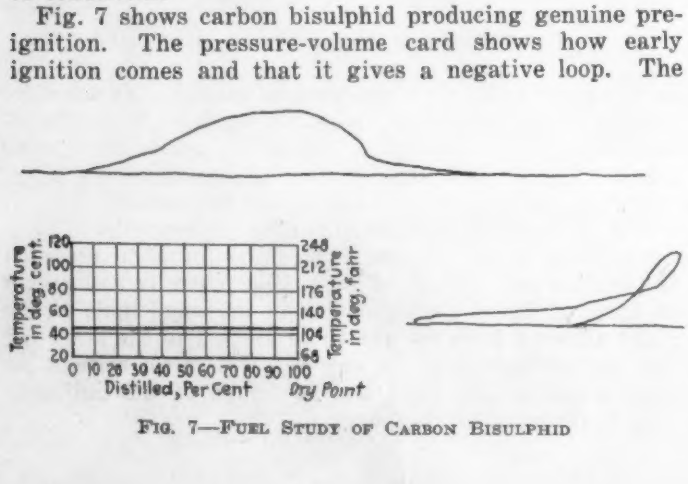


FIG. 7—FUEL STUDY OF CARBON BISULPHID

material is very volatile and boils at about 46 deg. cent. (115 deg. fahr.). A very early rise in pressure and a sudden drop-off are shown, but there is no trace of a knock. This fuel will run the engine and stop it, by preignition, as quietly as though the switch were turned off, except for the spitting back through the carbureter. There is no mechanical noise whatever.

Sulphuric ether, shown in Fig. 8, behaves differently. The curve rises smoothly along compression but, shortly after ignition, something happens. This is the knock, the noise of which can be heard across a 10-acre lot. There is a very sudden rise, then a drop-off and so on down. The structural formula for sulphuric ether, with the oxygen in the middle, and the distillation curve of the material are shown. It is very volatile and boils at about 35 deg. cent. (95 deg. fahr.). The rise in the

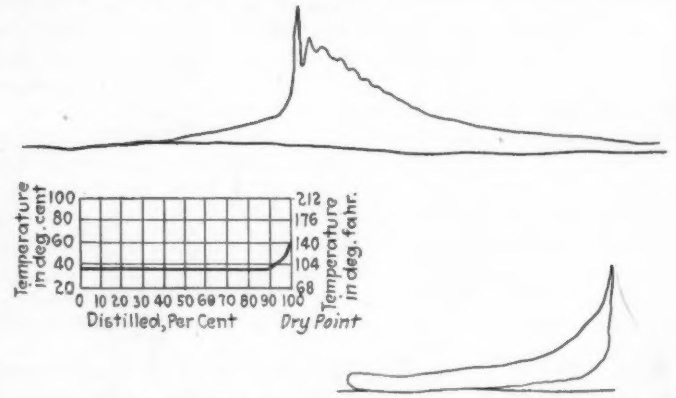


FIG. 8—FUEL STUDY OF SULPHURIC ETHER

distillation curve at the end indicates a trace of alcohol and water as impurities in the ether.

Fig. 9 shows a card made with butyl alcohol. Butyl alcohol has the same number of carbon, hydrogen and oxygen atoms as sulphuric ether, but the oxygen is in a different place. The knock has disappeared from the fuel and, when run even on high compressions, there is no knock whatever. The distillation temperature closely approximates 120 deg. cent. (248 deg. fahr.). Sulphuric

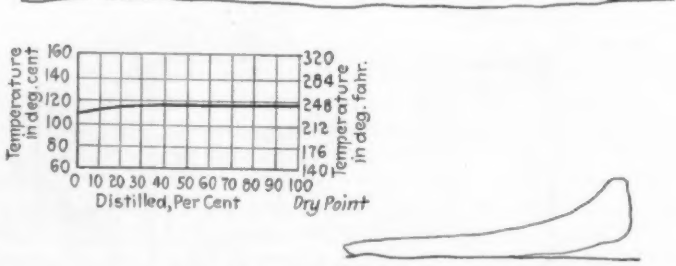


FIG. 9—FUEL STUDY OF BUTYL ALCOHOL

ether, which is very volatile, knocked; butyl alcohol, which was not volatile, did not knock. Can knocking be associated with volatility? It cannot. It functions only within an homologous series. The ultimate composition, or the total number of carbon, hydrogen and oxygen atoms involved, was exactly the same with both ether and butyl alcohol; so, we cannot depend on ultimate composition to tell us what causes the knock. We have the same proportion in both fuels, yet one knocked and the other did not.

We will now run over the petroleum products and show

their different behavior in this engine. This is an engine that does not knock on gasoline, although if the compression were raised it would knock. Fig. 10 shows fuel studies of gasoline and kerosene. The general formula of each is a long chain structure which is given in Fig. 1 on page 491. Gasoline from Pennsylvania crude, which is a straight paraffin-base gasoline, and kerosene from Pennsylvania crude oil are shown. The distillation curve of kerosene is higher than that of gasoline because it is a heavier fuel. The chain of its structure is longer and, when run in the engine, it shows a decided knock. The knock as given by kerosene is slightly different from that

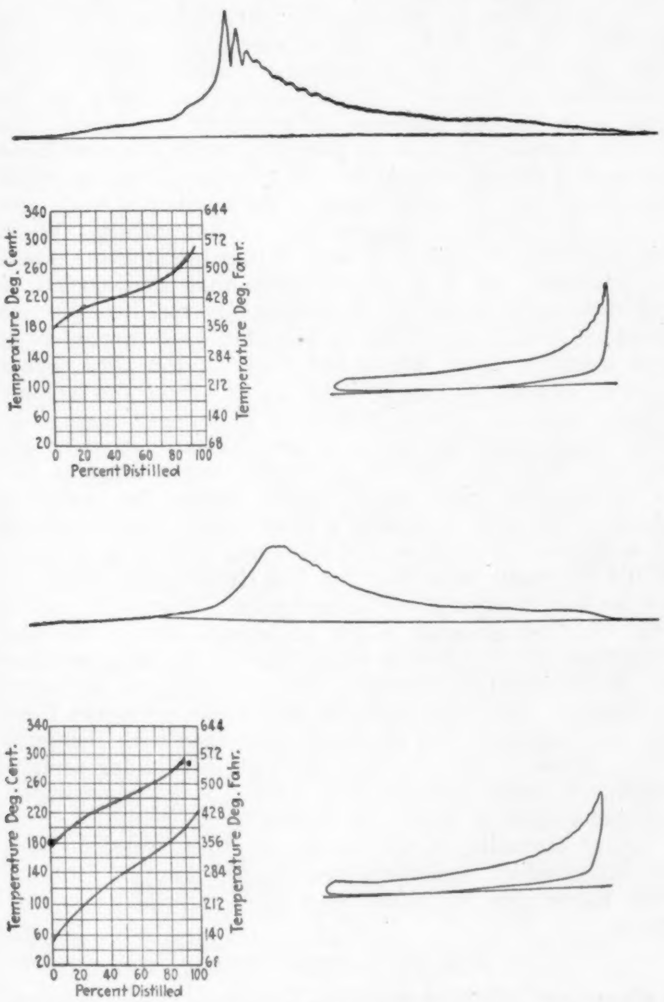


Fig. 10—Fuel Studies of Kerosene (Above) and Commercial Gasoline (Below) Obtained from Pennsylvania Crude Oil

given by ether. With ether there is only one "kick-up" and then the curve comes down evenly. With kerosene there are two peaks. This means something that should be investigated.

Fig. 11 shows fuel oil in the same engine. The distillation curve is still higher and the indicator card has five distinct kick-ups instead of one or two. The number of kick-ups is to a very large extent a measure of the volatility of the fuel; that is, provided the fuel knocks. As the fuel gets "heavier," more kicks are given off from the knock.

Fig. 12 shows gasoline that has been made by cracking a heavier oil in a Rittman furnace. It contains the olefins I mentioned, which have double bonds formed in the cracking process. This gasoline is a good fuel so long

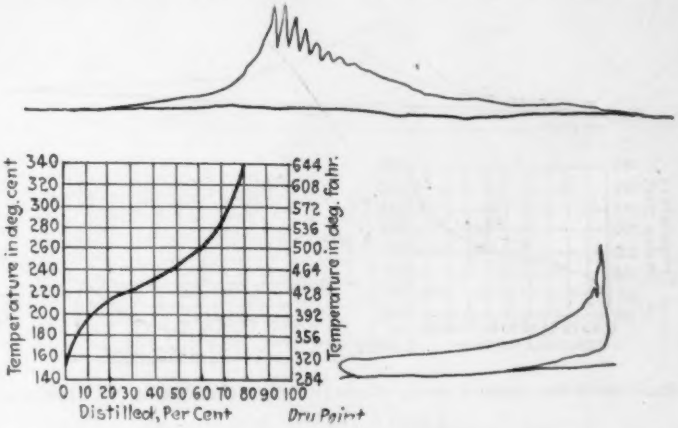


Fig. 11—Indicator Cards Obtained from an Engine Burning Fuel Oil

as it is fresh. In time, many of these compounds make tars which separate out on the intake valve and give trouble when they are run in an engine.

Fig. 13 on page 494 shows California gasoline containing the so-called naphthenes, of which cyclohexane is one. It contains about 40 per cent of this type of compound against 60 per cent of paraffins. We still have the paraffins to contend with, but this fuel will stand much higher compression pressures than Pennsylvania gasoline. We had no trouble running Liberty engines at 6.5 to 1 compression on ordinary California gasoline.

Fig. 14 on page 494 shows a special fuel prepared by hydrogenating benzol so as to get a pure hydrocarbon fuel that would stand high compression pressures. It was a mixture of cyclohexane and benzol, called hecter. Cyclohexane freezes at about 40 deg. fahr.; benzol freezes at about the same temperature. If such a fuel were put in the tank of an airplane and taken up to a 15,000-ft. altitude, there would be a chunk of ice in the fuel tank. We had to stop this freezing. We found that 80 per cent of cyclohexane and 20 per cent of benzol gave a mixture that did not freeze until the temperature reached 40 deg. below zero fahr.

Fig. 15 on page 495 shows commercial benzol. It produces a very good burn. Like alcohol it can be run at high compressions, and it is burning properly so far as the card is concerned, but it has other undesirable features. It is so rich that carbon separates out in one or two cylinders and lies there as a black, fluffy deposit. This material is not a carbon deposit as we ordinarily term it; it will get in a spark-plug, cause it to miss a couple of shots and then it will blow out; and it will do this same thing again and again. We can find nothing radically wrong with the engine, and for that reason it is generally unsatisfactory. But if not to exceed 40 per

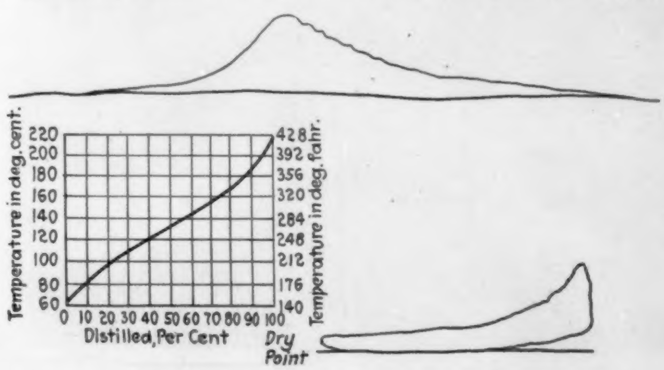


Fig. 12—Fuel Study of Gasoline Obtained by Cracking a Heavier Oil in a Rittman Furnace

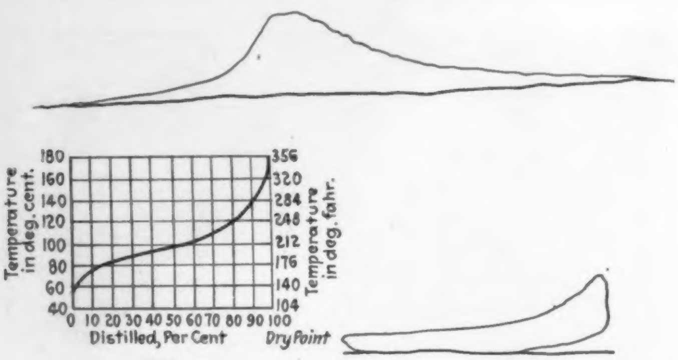


FIG. 13—FUEL STUDY OF A GASOLINE OBTAINED FROM CALIFORNIA CRUDE OIL

cent of benzol be blended with gasoline, it makes a very noticeable improvement in the gasoline and does not cause the fluffy-carbon trouble.

Development of the Theory of Knock

When we had completed these experiments, there was little cause for accepting any of the old theories as to what the knock is. We knew it was not caused by auto-ignition; or by the ultimate composition of the fuel; or by burning ahead of the point at which ignition should occur by means of the spark-plug, because it came *after* the spark-plug fired the mixture. We knew many things that the knock was not but nothing that it is.

A theory is valuable according to what can be got out of it that can be applied in a practical way. We had one theory that absolutely was not correct at all, and yet it was perhaps the most valuable theory we ever had. Kerosene knocks and gasoline does not knock. Imagine that a charge of liquid kerosene, broken up into small particles, is drawn in and begins to burn, and that as it burns the temperature and the pressure both rise. The temperature tends to make the fuel boil and the pressure tends to keep it from boiling. Finally the pressure does not rise any more but the temperature is still going up. The small particles evaporate and burn all together and this makes the knock. We theorized, consequently, that if these little transparent particles could be heated somewhat faster than normally this would not occur. If instead of being transparent they were dyed black, or some other color, they could then intercept some of the radiant energy in the cylinder-head and could be heated faster so that, during the pressure rise, they would boil slowly instead of all going off together. Not having any oil soluble dyes readily available, we tried iodin as a coloring medium and found that the knock was eliminated. Later we tried dyes, but they had no effect. This, of course, proved that our theory was not correct; yet it had been a very good theory because we discovered that a small percentage of a substance could be added to a fuel and thus stop the knock. Later, we began looking around for some compound other than iodin, which would be cheap and overcome other difficulties of iodin. We tried several hundred different compounds. Every time we heard of a new kind of organic compound, we obtained some of it. One day anilin was tried. Instead of pouring it into the gasoline as ordinarily we heated the anilin with the gasoline, thereby getting it into solution, and it also stopped the knock.

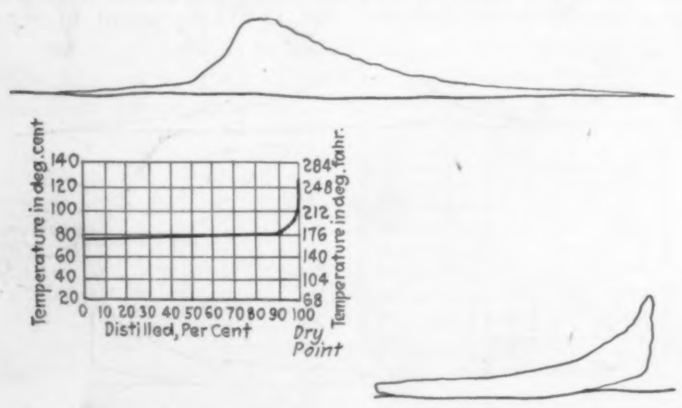


FIG. 14—FUEL STUDY OF HECTER, A SPECIAL HYDROCARBON FUEL THAT WILL STAND HIGH COMPRESSION PRESSURES

In attempting to interpret the physical meaning of the sudden rise and sudden fall of pressure as indicated on the card taken from a knocking cylinder, we reasoned somewhat as follows: This phenomenon could not be due to a sudden increase in pressure throughout the entire charge. Increase in pressure, under the conditions present in the cylinder at the time the knock occurs, could be caused only by an increase in the number of molecules of gas present or by an increase in temperature. While the occurrence of either or both of these phenomena might be conceded, yet it is inconceivable that they should be followed immediately by the sudden reversal necessary to produce such a rapid fall in pressure as is recorded on the indicator card, where the peak on the card occurs almost exactly at upper dead-center when the volume change due to piston movement is almost negligible. How then could this peak on the indicator card be accounted for? The answer is simply that it must be due to a pressure wave which passes across the indicator piston. The only way such a thing could occur would be by a detonation of some sort occurring within the charge. It did not occur to us that the fuel itself might detonate; so, we had to stretch our imagination. It was suggested that the fuel molecule might be broken down under the conditions present during combustion, with the formation of an intermediate product that was capable of being detonated. This idea received considerable support from the observed fact that the knock increased with temperature. Since it was known that acetylene under certain conditions would detonate and, since it is an unsaturated substance such as might be formed by splitting off from a larger molecule, it was suggested that acetylene was the intermediate substance causing the knock. But we were never able to isolate any such intermediate substance.

The Theory of Knock

When Mr. Horning and Dr. Dickinson went oversea they met Dr. Dixon, an English physicist, who had done some remarkable research work on the explosion of gases in mines. Fig. 16 shows one of Dr. Dixon's photographs of a wave-front, which is clear and sharply marked. Behind it is a region of light. He had an apparatus so constructed that the angle of the wave-front in the photograph indicated the velocity of travel of the wave-front. Fig. 17 shows how complex these waves can become. One wave comes down, strikes the bottom of the tube and reflects back, just as a rubber ball would bounce. It is not traveling so fast on the way back as it did on the way down.

Mr. Horning and Dr. Dickinson obtained from Dr. Dixon considerable information about the explosion of these gases and they connected the results of Dr. Dixon's work with our detonation theory. Dr. Dixon had proved that these fuels themselves could be detonated without any intermediate compound. We put the acid test to this

theory, and in so doing we have absolutely convinced ourselves that it is correct.

Dr. Dixon showed several years ago that in a long tube filled with an explosive mixture of gas which was fired at the near end, the velocity of flame propagation was not a constant but accelerated to a very high velocity. Translated from meters, this velocity is about 1 mile per sec. Dr. Dixon's calculations would indicate that the pressures on the wave-front are about 100,000 lb. per sq. in.

Detonation is a pressure wave traveling through a gas. True detonation means that the wave travels so fast that the energy liberated by burning the fuel in the wave-front cannot be dissipated. Instead, it builds up pressure and adds energy to the wave-front, which later hits the side of the cylinder-head with a tack-hammer blow. This is the knock. It does not injure the rods, because it is completed too quickly.

We wished to repeat some of Dr. Dixon's work for our own observation; so, we filled a glass tube with an explosive mixture and lighted it at the near end. The test as to whether it detonated or not was to put a glass test-tube over the far end; if it detonated it broke the test-tube; if the velocity of the burn did not reach the velocity of detonation, the test-tube was not broken. Whether or not detonation occurred, the noise produced was about the same. We prepared this apparatus and fired it a dozen times or so. We had been suspecting that the flame was not the same color all the way through, so we trained our eyes to watch it. We found that it started out blue, became yellow about the middle and white as it approached the end of the tube. We believed that so long as the flame remained blue there was no detonation. We tested this point and found that when the flame remained blue throughout the tube, the test-tube was not broken. We previously had put a window in the side of an engine cylinder so that we could watch the flame. We ran the engine when it was somewhat cool and thoroughly clean. The flame was blue and the engine did not knock. When the same cylinder was a little warmer and running on the same fuel, it did knock and the flame was white. We studied these two flames with the spectroscope. When the engine did not knock we had a spectrum with about six lines; but when it did knock spectroscopic analysis showed that free carbon was present. This can be checked up on any aviation engine that is knocking in one or two cylinders. Synchronously with this knock comes a fine black dust which is not smoke.

The differential burn between alcohol, showing a blue flame, and gasoline, showing a yellow flame, has been illustrated. The yellow flame indicated that the oxygen preferred the hydrogen. If the carbon cannot get oxygen quickly enough under those conditions, how can it get enough at a velocity of 1 mile per sec.? It cannot do it; free and incompletely burned carbon results. The flame starts out blue, indicating that everything is being burned; as it speeds up it gets a trifle fast for the carbon and some of the carbon drops out; when the flame becomes white nearly all of the carbon has been left behind.

Suppose we have a molecule somewhere within this tube, and that the wave-front hits it. The first thing the wave-front must do before the oxygen can gain access to the hydrogen or the carbon is to break up the molecule. To do this the wave-front must give up energy; this results in slowing its speed down somewhat. After this has happened, the hydrogen is accessible to the oxygen that is present. The wave is going too fast for the oxygen to burn the carbon in front of it; so, it leaves the carbon behind and free carbon shows in the spectrum.

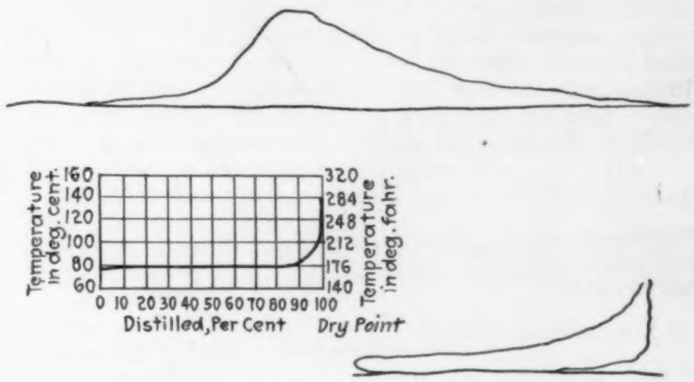


FIG. 15—FUEL STUDY OF COMMERCIAL BENZOL

The wave-front recovers the energy which results from the burning of the hydrogen, but the carbon is not burned. In other words, the wave-front of detonation meets the fuel molecule and gives up energy to break it up, which is the heat of formation of the compound. It receives energy from the combustion of the hydrogen, the heat of combustion of the hydrogen, but not of the carbon. Thus, the energy given to the wave-front in excess of what it had is the heat of combustion of the hydrogen, minus the energy required to break up the molecule. If the heat of combustion of the hydrogen is greater than that required to break up the molecule, the wave receives additional energy to that which it had when it met the molecule. We can call this difference the "excess energy of detonation." We can calculate the heat of formation and the heat of combustion of the hydrogen from the structural formula. Then we can calculate the excess energy of detonation for the combustion of a given volume of gas and determine which fuel will cause the worst knock. The one that has the greatest excess energy of detonation will be the worst knocker, as is shown in Fig. 18 on page 496.

Table 1 shows some fuel studies, exactly as made for a report prepared during the war. The fuels are arranged in the order of their tendency to knock. We found that the ethers were the worst knockers; the paraffins, which are the ones we must use, come next; the olefins are considerably better than the paraffins, and the naphthenes are still better than the olefins; then, in order, come the aromatics and the alcohols. The disadvantages of the various types of fuel are shown in Table 1 on page 496.

FIG. 16—A CLEAR AND SHARPLY DEFINED EXPLOSION WAVE-FRONT

FIG. 17—AN EXAMPLE OF HOW COMPLEX A WAVE-FRONT CAN BECOME

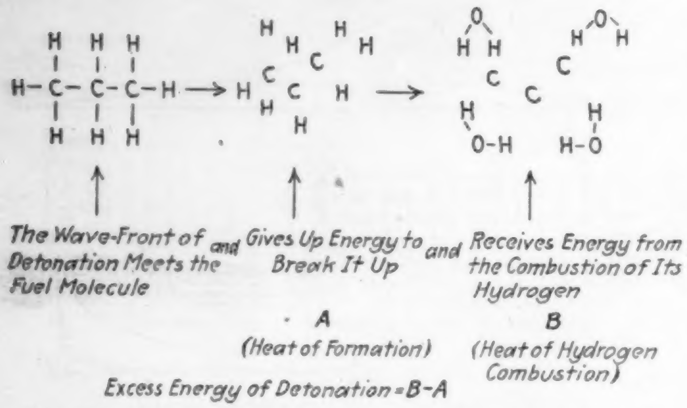


FIG. 18.—DIAGRAM SHOWING THE EXCESS ENERGY OF DETONATION

Table 2 shows the energy liberated during detonation, calculated as previously explained. Put down opposite these fuels, which are arranged in the same order as in Table 1, are figures showing the calculated relative tendencies of the different fuels to knock. These values arrange themselves in almost exact accord with the previously determined decreasing tendency of the fuels to knock. We adopted a percentage basis and took a certain cubical content of fuel mixture that would give ether a value of 1000. On this basis the paraffins run 860; olefins 805; naphthenes 780; aromatics 545, and alcohols 620.

TABLE 1—FUEL STUDIES

Fuels	Disadvantages
Ethers	Pre-ignition
Paraffins	None, if volatile
Olefins	Polymerize and stick intake valves
Naphthenes	None, if volatile
Aromatics	Form fluffy carbon
Alcohols	Low heating value

This is close enough to be encouraging, although there is a slight discrepancy at the last.

Probably this discrepancy is one of the things that led us to reason why anilin stops the knock. Down to aromatics in Table 2, the values had been determined by actually running the pure fuel in an engine and finding out what compression it would withstand; but when we reach the aromatics, the compressions, if there are compressions that will make these fuels knock, are very high and far beyond what we could use mechanically. In the cases of gasoline and kerosene, we knew that kerosene knocks much worse than gasoline. We theorized, therefore, that since we could blend 60 per cent of benzol with kerosene and make it equal to the gasoline and since it requires only 35 per cent of alcohol to do the same thing, certainly alcohol must knock less than benzol. By blending, we found out which chemical substance we had to use the least of to get a certain result in prevention of the knock. This was satisfactory until we knew about the theory of detonation.

Benzol has a strong molecular structure and it is difficult to break up its molecule. Suppose the detonation wave passes through a vaporized mixture of benzol and kerosene containing sufficient oxygen for combustion; suppose that the wave-front meets a molecule of kerosene, that this molecule of kerosene breaks up and that the wave-front "feeds" upon its hydrogen; but suppose that the benzol molecule is so strong that it refuses to break down in the wave-front. It would, therefore, allow the wave-front to pass on and it would burn in the ordinary way. Consequently, we would not get the advantage of having the heat of formation of the benzol absorbed from the wave-front. We thought we were blending the benzol with the gasoline, but when it entered the cylinder it fooled us. One fuel burned at one time and the other burned at another time. Is it not therefore reasonable to suppose that the fuel which is bound together more strongly will be the poorer blending agent of the two; and that the fuel which is bound less strongly and has the lower heat of formation will be, or may be, a better blending agent but a worse knocker than benzol? This is how we explain the fact that our original arrangement on the chart was not strictly correct. It was due to the fact that the order was determined by blending which should give just the reverse results.

TABLE 2—ENERGY LIBERATED DURING DETONATION

Fuels	Excess Energy Liberated During Detonation
Ethers	1000
Paraffins	860
Olefins	805
Naphthenes	780
Aromatics	545
Alcohols	620

THEORY OF KNOCK SUPPRESSORS

The question always arises as to why anilin and iodin stop the knock. If the detonation theory as stated thus far is accepted, I think I can tell why anilin stops the knock. We can calculate the anti-knock value of anilin just as we calculate the knocking value of fuels; but I cannot tell why iodin stops the knock. This can be illustrated by putting anilin on one wick and ethyl iodid on another wick and trying to light them. The anilin burns easily in this way. It has about the same volatility as kerosene. We see a great amount of carbon because anilin is rich in carbon, since it is made from benzol. We observe something different in the case of ethyl iodid, although it is even more volatile than ordinary gasoline. We see that the ethyl iodid puts out the match flame.

We found that all the compounds of iodin stop the knock. Even potassium iodid will do it, if dropped into the intake valve. Although ethyl iodid extinguishes the flame of the match, it has a perfectly definite, positive heating value. If ethyl alcohol burns, ethyl iodid also should burn; but there is something that iodin does in a catalytic way that tends to stop the hydrogen from combining with the oxygen. What happens when we put the iodin in, or why it happens, we do not know. It prevents this detonation from occurring; it must do so because it does stop the knock. Carbon tetrachlorid has no appreciable heating value, yet if a small amount of it be admitted to a knocking cylinder of an engine it shows no effect similar to that of the ethyl iodid in preventing the knock.

To explain why anilin stops the knock, suppose we consider a paraffin molecule and a benzol molecule. It will be remembered that the excess energy of detonation depends upon the number of bonds that must be torn apart, as compared to the number of hydrogen atoms which burn and give back energy to the wave-front. In the paraffin molecule we have eight hydrogen atoms and a total of 10 bonds, which is a ratio of 8 to 10. The units comprising the 10 bonds are much smaller than those comprising the eight; that is, much more energy is recovered from burning one hydrogen atom than is absorbed by the breaking of one bond. If this were not true, the material could not be burned. In benzol there is a total of 15 bonds and only six hydrogen atoms, which gives a

ratio of 6 to 15, as shown in the graphic formula for benzol. (See Fig. 1 on page 491.)

We can calculate on this basis, using Table 2, that kerosene, for instance, which is 870, with about 3 per cent of benzol added to it, should average about 860. That is, 3 per cent of 545, plus 97 per cent of 870, will total close to 860. If this theory is correct, 3 per cent of benzol added to kerosene ought to stop the knock. Experiment shows, however, that, instead of 3 per cent of benzol, 60 per cent is required.

This is another discrepancy that must be explained. To repeat the theory as developed in the case of blending, imagine that a wave-front strikes these two molecules, breaks one all to pieces and feeds on its hydrogen; but the other molecule is held together more strongly and does not break down. We know that it requires a temperature of 200 to 400 deg. cent. (392 to 752 deg. fahr.) higher to decompose benzol than is required to decompose kerosene. In this case its bonds have no chance to hold back the wave-front of detonation. It may be possible that the benzol burning immediately in the rear of the wave-front keeps it from dissipating energy to its rear and thus tends to maintain it.

Suppose that something could be done to the benzol ring to make it less stable than the paraffin, or that it could be timed so that it would break down at just the right instant to engage the wave-front. We can add an NH_2 group to the benzol ring and thus make anilin, which is less stable than gasoline. Now suppose we put 3 per cent of this material into the kerosene. It immediately stops the knock and makes the kerosene equal to gasoline, thereby following the calculation without any variation. We say this is the reason that anilin stops the knock. We cannot calculate ethyl iodid but we can at least make ourselves believe that we calculate anilin. We can carry this further and check up our calculations by taking another knock suppressor. We found that as long as we had a ring and an NH_2 group we had a knock suppressor. We took naphthalene (see Fig. 1 on page 491), which has a total of 24 bonds and only eight hydrogen atoms. If we had three more bonds in the 6 to 15 ratio of benzol, referred to above, it would be the same as 8 to 24 or as one is to three. Therefore, naphthalene, having the 8 to 24 ratio, ought to be somewhat stronger than anilin, molecule for molecule, after we have added an NH_2 group to it and made it into naphthylamin.

I calculated this out and had determined the percentage of naphthylamin necessary to stop the knock in the engine at the same time. We had a value, as I remember, of about 65 units of some kind in 100 cc. of kerosene. That was the 6 to 15 ratio. The 8 to 24 ratio I calculated ought on the same basis to come to 48. It was determined as 49, which is about as close as anything can be determined on an engine.

The Discussion

D. L. Arnold:—Why is it that water accomplishes the same result as anilin and iodin?

Thomas Midgley, Jr.:—It does not. To duplicate the effect of 3 per cent of anilin would require 30 per cent of water.

Mr. Arnold:—Kerosene-engine builders have used water in the amount of an equal weight of water to an equal weight of kerosene, for eight years.

Mr. Midgley:—That is 100 per cent, somewhat different from 3 per cent.

Mr. Arnold:—And it has that effect, too.

Mr. Midgley:—Absolutely. It calculates right on taking the heat of vaporization of the water for the amount of heat that is to be taken out of the wave-front; that is, the heat of vaporization, which is small compared to the heat of formation. We are doing the same thing in both cases; we do it by the heat of vaporization in the case of water as against the heat of formation in the other molecule. If water dissociated at these temperatures, it would be as effective as anilin or anything else.

Mr. Arnold:—If too much of any of the fuels is used, that same knock is stopped.

Mr. Midgely:—The fuel itself acts in just the same way. When it gets in front of the wave-front it breaks down.

Mr. Arnold:—Why did the carbon tetrachlorid increase the knock?

Mr. Midgley:—I do not know.

Mr. Arnold:—Is it not because too much carbon was added to the flame?

Mr. Midgley:—No; only a breath of carbon tetrachlorid was used. It could not have been more than 1 per cent.

Mr. Arnold:—Is it not a fact that anything that is put in the combustion space that tends to diffuse the gas or vapor, such as an excess of air, will have the effect of discontinuing the knock?

Mr. Midgley:—Anything that will take energy out of the wave-front will slow down the knock. Try to run sometime with about 30 per cent of oxygen.

Mr. Arnold:—With an excess of oxygen?

Mr. Midgley:—Yes.

R. B. Hall:—If water is used to reduce or eliminate the knock, is there a power loss due to the retardation of the wave-front or is that power again given up on the expansion stroke?

Mr. Midgley:—No power is lost in retarding the wave-front. The carbon in the wave of detonation is not being burned. If the carbon is not being burned, we are not getting the heating value from the carbon and consequently we are losing much energy in that way. Water will slow up the wave-front. The carbon burns along with the other components and we then get the power from the carbon. We never found any loss of power in all our water-injection work, unless we ran with an excess of water.

Mr. Hall:—In that way, water would be a very good means to reduce or stop knocking, would it not?

Mr. Midgley:—Absolutely; but there are a few drawbacks. One is that water freezes. We can add alcohol and stop water from freezing, but that alcohol would burn up. The result would be that the cost, at the present price of alcohol, would very nearly reach the cost of gasoline. With tractors, this is not so much of a problem, because the water can be poured in when the tractor starts. I think water may be the right thing for tractor use.

Mr. Arnold:—We formerly built tractors to use water but do not use water now.

Mr. Midgley:—That is all the better.

Mr. Arnold:—We can carry the same compression.

Mr. Midgley:—In winter it is very difficult to meet the situation with water. I have heard the objection made, although I have had no personal experience with it, that in various parts of the country the water is a serious thing to contend with. One gets sulphur water in Florida, alkaline water out West and so on.

Mr. Arnold:—It is true that one gets all kinds of water and experiences all sorts of trouble on that account.

F. C. Mock:—It might add to our conception of what turbulence does if we consider how slow the velocities of flame propagation are in comparison with the velocity of

the gases through the intake valve at high speed. I believe that the propagation of flame in an explosive hydrocarbon mixture, under atmospheric pressure, for the first 6 in., is so slow that it can be seen. If the mixture is compressed or heated, the velocity increases. Dr. Dickinson's experiments with the Liberty engine at the Bureau of Standards showed that the flame propagation is considerably less than the velocity through the intake valve.

MR. MIDGLEY:—I think it was 20 meters per sec., but when they got detonations they could not measure the velocities.

MR. MOCK:—It is easy to imagine that part of the entrance velocity of the air charge persists through the compression stroke, as a whirling motion of perceptible magnitude in relation to the first velocity of flame propagation. In such a case the combustion wave-front might be considered as trying to propagate itself across a merry-go-round of mixture whirling rapidly, and it would naturally have some trouble getting aboard. That is, the wave-front, as such, would be broken up, and acceleration of its propagation would be impeded.

We have reason to believe that the mixture is not evaporated until it enters the cylinder, which would cause a lowering of temperature in the cylinder. Is this subtraction of heat from the walls and mixture appreciable and comparable with the heat required for this breaking of the chemical bonds?

MR. MIDGLEY:—Yes. When we put in sufficient hot-spots to actually vaporize and send in the gasoline as a vapor, the knock very appreciably increased. The experience I have particularly in mind was with a Delco light plant, in which there is no distribution to fight, and which keeps down the temperatures and thus helps to prevent detonation. In this connection let me refer to one point which I failed to treat properly, the effect of temperature on detonation; that is, temperature as compared with pressure. I am firmly of the opinion that temperature is the prime factor in speeding up these detonations, and not compression. It is pointed out very clearly by Dr. Patrick that a hydrocarbon gas, while being compressed close to its dew-point, gives tremendous rises in temperature as the gas approaches the dew-point. It need not condense to give 200 to 300 deg. cent. (392 to 572 deg. fahr.) rise in the temperature due to compression. It is probably due to this change in temperature that kerosene knocks worse than gasoline, and not primarily to a chemical reason. Taking the opposite viewpoint instead of asking why kerosene knocks more, let us ask why gasoline knocks less. Gasoline is a fairly volatile liquid. When it is evaporated it absorbs heat and cools itself. It is the refrigerating effect of the gasoline that holds down the detonation.

MR. MOCK:—That answers the question I intended to ask, as to why the carbureter and the intake manifold are fixed so that they feed a homogeneous mixture to the cylinders and the engine knocks less.

C. A. FRENCH:—What mixture ratios were you experimenting with when you obtained detonation in the glass tube?

MR. MIDGLEY:—Theoretical.

MR. FRENCH:—Do you never give the mixture more air than the theoretical amount?

MR. MIDGLEY:—Yes. Running lean cuts down the detonation. We can run rich enough to stop it and also lean enough to stop it. We could do that not only in the glass tube but also with a certain automobile that is a violent knocker. During experiments on distribution and heating on this car, we were able to get a condition of actual heating in which the gasoline was probably all gas, and distribution did not cause any trouble. We could lean the mixture so we had no knock, just as we can ordinarily enrich it. Most cars will not work with such a lean mixture; they go out. We lost all the pick up and the car would not accelerate, but it would not knock.

MR. FRENCH:—With reference to detonation in the open air, no compression or particular temperature is needed to get detonation, according to our experience. I have a burner at our plant on which I hope to be able to play a tune. It can be heard from 1/4 to 1/2 mile. I have ordered a siren to tune up to it, to determine what rate of vibration produces that noise. The burner is primarily a blue-flame burner. I think that any burner giving a blue flame in which there is considerable previous vaporization can be made to scream, hum, whistle or make some protest when it is given too much fuel. I can find no authority anywhere for assuming that we can burn theoretical mixtures to perfect combustion. It seems that in our worship of volumetric efficiency we are forgetting a few things about combustion. There was not much doubt 25 to 30 years ago about what we had to do to burn the different fuels. We thought we had to vaporize them. It seems that we have an entirely different idea today. To go back 25 years is the only way in which we can make an atmospheric burner that is at all efficient. If we attempt to put raw fuel out into a combustion-chamber and burn it, we require a combustion-chamber of about 0.2 cu. ft. fuel capacity for every pound of fuel burned per hour. The luminous part is not flame; it does not come within the definition of flame. All the visible flame of common fuels is blue. The luminous part is merely incandescent carbon particles that are not in a state of combustion. The combustion-chamber, to have the best possible combustion, must be large enough that the flame does not touch it anywhere if there is to be luminosity. If that condition is fulfilled, we require 0.2 cu. ft. of combustion-chamber space per lb. of fuel per hr. burned continuously. A combustion engineer would say that there could be no worse place to burn an excess of fuel than an internal-combustion-engine cylinder unless it were the center of a barrel of water, because every unfavorable condition is present. We have never had any trouble from decomposition, provided we did not use an excess of fuel or, provided we put into the transparent area or period of that flame something into which the carbon could diffuse at the time it broke down. If the theory is correct that there is a certain temperature at which it breaks down, then if we feed hydrogen into the transparent part of the flame, the detonation or decomposition should occur sooner, because that raises the temperature. In fact, if a thermocouple is put in a candle flame below the point of decomposition, we find it is much cooler there than it is farther down. The whole trouble seems to be based upon the fact that we are doing everything we can to keep on using too much fuel.

I think that the theory of putting the compression pressure up to 200 lb. per sq. in. is absolutely correct. We can burn kerosene at 200 lb. per sq. in. without any difficulty if we put air enough in to burn it. We must sacrifice some of the pick-up.

We have had no trouble in burning the different fuels in atmospheric burners. I cannot conceive that there is any difference in flame, wherever it is; it must obey the same laws. We can put any commercial fuel into a burner that thoroughly vaporizes the fuel previous to ignition; it makes no difference what it is. I think no one can tell what fuel it is by the way it burns. They all burn alike. The troubles we have in combustion are entirely according to the end-points of the fuel. I am unable to say why

ether knocks in the way it does, unless a great excess of it is used. Have the ether ratios been measured?

MR. MIDGLEY:—Yes. Ether cannot be made lean enough that it will not cause knock.

MR. FRENCH:—I will not argue that point. There is more tendency toward decomposition in some fuels than in others but, so far as we have put them all in equal states of vaporization, diffusion and proportion, we have had exactly equal results with them. It has been demonstrated that a cubic foot of any gas mixture gives the same number of British thermal units regardless of what the gas is.

MR. MIDGLEY:—That is in atmosphere.

MR. FRENCH:—Yes.

MR. MIDGLEY:—That is not true under compression.

MR. FRENCH:—I can imagine that compression would change some of those things.

MR. MIDGLEY:—What have you done with acetylene?

MR. FRENCH:—I have not worked with it.

MR. MIDGLEY:—You will find it is easy to detonate with acetylene. Let me suggest that with the acetylene you try a rich oxygen content of air to help it along. At atmospheric pressure, the fuels will all behave practically the same, unless the conditions are unusual.

MR. FRENCH:—We are able to produce detonation in the open air.

MR. MIDGLEY:—Are you sure that it is the same kind of detonation?

MR. FRENCH:—I imagine there is no difference. It seems more reasonable to account for the knock by the sudden difference in the temperature of the flame. I have measured many times the difference in flame temperatures in passing from the transparent to the luminous area. The sudden jump of 1000 or 1500 deg. in going a few inches in an open flame, and of course the same thing takes place in an engine cylinder, seems to account for it. The fact that there is no area to that sharp peak on your indicator card would indicate that it is a carbon phenomenon, because there are not many British thermal units in the carbon and there are many in the hydrogen. If it were an hydrogen phenomenon it would blow the cylinder-head off.

MR. MIDGLEY:—With regard to the breaking up of an engine on account of detonation, this viewpoint was held by a man who is with one of the large explosives companies of the country and with whom we have been cooperating on some of this research work. He spent 25 years studying detonation in explosives. He said that there is no truth in this detonation theory because, if it were true, it would wreck the engine. We argued that he was detonating in dynamite, a material that is very dense compared with the gas in the cylinder, even when it is compressed; but he maintained that detonation would break an engine all to pieces, and that the knock must be caused in some other way.

A Liberty engine having a compression ratio of 5.3 to 1 was set up at McCook Field. Ordinary automobile gas instead of high-test gasoline was used for an hour, with wide-open throttle. At the end of the hour the engine was dismantled. Every spark-plug was found to be injured, because portions of them are very brittle, and most of the piston-heads were cracked, having been hit by this detonation.

MR. FRENCH:—I can understand the effect of reverberatory action between parallel surfaces in combustion-chambers. If I want to build a combustion-chamber for the highest temperatures, I build it in spherical form. Of course, the high temperatures would not be set up in a furnace or a combustion-chamber without parallel surfaces because the temperature, in a measure, is self-generating; the radiant heat working back and forth through the burning mass helps to generate it.

I will agree to your definition of detonation for the time being, because I cannot contradict it successfully; that is, I will agree to your calling it detonation. But we use acetylene for welding and cutting because, while it liberates a small quantity of heat, it has the highest temperature of anything that we can get, on account of its very high carbon content. We do not use hydrogen for the reason that, while it has a fair temperature, its temperature is nothing like carbon, and it liberates so much heat that we cannot work around it.

It seems to me, from the characteristic of that point we get on the card from the knock, that this indicates carbon entirely. Possibly you will agree that it is a carbon phenomenon; but the fact that there is no appreciable carbon area simply shows a temperature, without the liberation of any great number of British thermal units. If we were able to do that same thing with hydrogen, we would have a remarkable engine.

MR. MIDGLEY:—What do you mean by "run an engine on hydrogen?"

MR. FRENCH:—I have never run an engine on hydrogen.

MR. MIDGLEY:—But that is a very good idea.

MR. FRENCH:—This matter of the knock is best explained by the sudden jump in temperature. We find it in all flame. As soon as we put in an excess of fuel, we find there is a great difference in the size of the yellow area and the transparent area below it or period preceding it, whichever it happens to be. We find that an engine running with a blue flame is running the way it ought to run, and the only way we can get it to run with a blue flame at present is to put in an excess of air. But anything that we add to the transparent area or period of the flame below or before the decomposition, that is, any gas into which this carbon can diffuse, stops the decomposition. I have tried nitrogen, hydrogen and almost every gas except pure carbon gases; a carbon gas would make it worse.

AIRCRAFT INSURANCE

CONSUL CLAIBORNE, at London, reports that Lloyd's, the foremost British insurance organization, has established a bureau to insure pilots, passengers and goods conveyed by air as well as aircraft themselves. A miniature register of aircraft analogous to Lloyd's Shipping Register, and known as Lloyd's Aviation Record, is employed as the basis for this new and important activity.—Air Service News Letter.

THE PETROLEUM OUTLOOK

ARTHUR D. LITTLE, INC., Cambridge, Mass., has announced that a limited number of copies of its monograph on The Petroleum Outlook are available for distribution. This study of American oil fields includes a large map and several charts arranged for comparative reference. The text deals with the geology, production history and apparent state of exhaustion of the various petroleum resources.

RADIO CONTROL OF BATTLESHIPS

REPORTS received at Bureau of Steam Engineering of the Navy Department regarding experiments conducted off Virginia Capes with the battleships Ohio and Iowa, that have recently been completed by the Navy, prove that 12,000 and 13,000-ton battleships can be successfully maneuvered from stations located on shore by the use of radio apparatus operating directly upon steering gear.

Washington Fuel Meeting

By Coker F. Clarkson

PRETTY much everybody who is "anybody" in the oil industry attended the annual meeting of the American Petroleum Institute held at Washington Nov. 17, 18 and 19. It was the occasion of continued and increased cooperation of the Society and the Institute. Past-President Kettering gave an epoch-making address as accredited spokesman of the automotive industry. Two technical sessions on automotive fuel and lubricants subjects were held, with H. L. Horning, chairman of the S. A. E. Fuel Committee, and H. M. Crane, a member of this committee, as presiding officers.

Mr. Kettering explained in detail to the oil men the difficulties involved in the vaporization of currently produced gasoline, preventing proper mixture distribution to the cylinders, and causing dilution of the engine oil. He said that under present conditions the best engines made are subject to crankcase oil dilution. He emphasized the great importance of getting the public to understand the many phases of car operation involved in the economical use of gasoline. He pointed out that naturally the public had been taking with little apparent complaint the fuel they have had to take, and the viciousness of the circle of procedure in lowering engine compression to use heavier fuel, then increasing the end-point of the fuel and then lowering the compression again. With a given fuel a certain compression pressure and a certain combustion temperature cannot be exceeded without abnormal results, including detonation. Economy depending on higher compressions, this constitutes the fuel problem. Mr. Kettering feels that the automotive engine and the fuel for it must be further developed by the automotive engineers and the oil engineers and chemists jointly. He referred to high pressures, high temperatures and the low specific heat of the fuel as the prime factors of internal-combustion engine operation. The demand is for a fuel and for lubricating oils that will not require engine cleaning. The molecular breaking of the fuel and too rapid burning must be obviated. Ultimately there should be a correction in the process of crude oil distillation. Mr. Kettering believes that by proper cooperation between the automotive and fuel industries these results can be attained quickly. In a word, the thing to do is to take the hammer-blow peak due to detonation out of the combustion curve.

In connection with the fuel "dopes" with which he has experimented for a long time, Mr. Kettering told at some length of their use and effectiveness, using the homely expression that any "varnish-remover" in a fuel dope, functioning as such an agent, will prevent carbonization.

Referring to engine starting under present conditions in cold weather, Mr. Kettering advocated the installation of auxiliary devices to prime engines with highly volatile substances such as petroleum ether.

On the thermal efficiency now being reached, the speaker stated that with the ordinary car this averages less than 5 per cent, being with wide-open throttle about 15 per cent. Further, that with 160-lb. compression, which he believes is possible, the fuel consumption can be reduced to 0.4 lb. per hp.-hr., the relative gain in this respect being greater at car speeds of 20 to 30 m.p.h.

In introducing Admiral Benson, chairman of the United States Shipping Board, President O'Donnell of the Institute predicted a great increase in the use of the internal-combustion engine in ocean travel. Admiral Benson stated that the fuel needs of the Shipping Board in 1921 would probably amount to 40,000,000 bbl. One hundred and two vessels, mostly oil-burners, are yet to be completed, 26 of these being of the high-speed passenger type. He said that foreign trade competition makes it clear that it would be a serious thing for the American merchant marine to revert to the use of coal and that a plentiful supply of fuel oil is necessary for the requisite economical operation. The Admiral believes that the present supply of oil is adequate. He favors the development of internal-combustion engines and the electric-drive for ocean-going vessels. We should have reserve supplies of fuel oil in all parts of the world. Long trips are now made for the purpose of bunkering. Development of oil lands in foreign countries is hoped for, mutual arrangements for the exchange of oil being made to obviate the present necessity of carrying oil to all parts of the world. Attempts are being continued to install in cargo-carrying vessels Diesel engines geared direct or with the electric drive.

General Conditions

Many very interesting and valuable addresses were made at the general sessions of the meeting. President R. D. Benson of the Tide Water Oil Co. said that

> Petroleum owes its present high place in industry to three things. First, the invention of the Lowe water-gas process, by which material for making illuminating gas was changed from coal to petroleum distillates; second, the invention of the internal-combustion engine which brought gasoline into its own; and, third, the development of the use of fuel oil in place of coal, notably on the high seas.

W. C. Teagle, president of the Standard Oil Co. of New Jersey, stated that

> It is a conservative estimate that the world consumption, which in 1910 took 327,000,000 bbl. and this year is using 615,000,000 bbl., will call for close to 700,000,000 bbl. in 1921. The indications are that in the current year we shall produce within our own borders 445,000,000 bbl., and consume, with Mexican imports, a total of 565,000,000 bbl.

The following observations were made in the address of Director G. O. Smith of the United States Geological Survey.

> In a review of the world's sources of energy, water and coal, as well as oil, we see North America taking first rank among the continents, with Asia a close second and Europe a poor third, although we should remember that Europe has a much smaller area than either of the other two. Now, in considering how the world may best manage its ever-increasing power load, some aid may be found in a few comments on the differences between these three sources of energy, water, coal and oil. Man has learned how to harness flowing water with great efficiency, but even in Europe and North America only about one-fifth of the potential power has yet been developed. Of course, even with wisest utilization, coal must again take up the burden as full development of waterpower is approached, for coal is the world's great source of heat and power, and

the largest development of water powers is practicable only with coal power as the dependable "stand-by," ever ready to meet promptly any special demand.

Fuel oil is superior for use in transportation, and this use deserves priority over that for firing stationary boilers, for which coal should be substituted. Indeed, thoughtful regard for the future leads us to disallow even the claim of steam locomotives for fuel oil, for electrification of the railroads by waterpower alone or from waterpower and steam stations linked together is now the obvious way to make the best use of our resources of expendible fuel. In a word, the world has not oil enough to burn under either stationary or locomotive boilers.

M. L. Requa of the Sinclair Consolidated Oil Corp. said that

Burned under boilers, fuel oil is at best wastefully consumed, and at worst is losing in every barrel 20 to 30 per cent of lubricating stocks that we shall some day need badly. Over any long period of time its future use in this manner is without excuse or justification. Employed as a fuel in the Diesel or semi-Diesel type of engine, the saving amounts to as much as 75 per cent of the oil burned; and economic pressure will, of course, force greater and greater use of this type of engine, especially for marine work. I seriously question whether the marine steam-engine is not today obsolete. Certainly with over 140,000 gross tons of Diesel-equipped shipping now under construction in the United States, and the large foreign fleets in operation or building, the Diesel type is no longer experimental and must, in future, I think, supersede steam-driven units with ever-increasing rapidity, because of absolutely economic reasons if for no other. A recent report of Lloyd's indicates that 16.3 per cent of the world's tonnage is now employing fuel oil, and already 1.7 per cent of the world's tonnage is converting fuel oil into power by the Diesel type of internal-combustion engine. Since the United States is planning a great expansion in foreign trade and is building a substantial merchant marine, we will ignore a most potent point of superiority if we neglect the significance that motorships have upon the situation.

President O'Donnell had an optimistic view of future oil supplies, and explained his reasons therefor, as well as conditions which have led to the present situation. He declared for "quality" as opposed to "quantity" science in the oil industry. In his words,

The public has been frequently alarmed by statements of well-meaning and learned scientists predicting an early exhaustion of our petroleum resources, in some instances giving more or less definite figures as to the supply still obtainable and setting a time for exhaustion within the limits of the lifetime of men now engaged in the business. There are many important petroleum deposits even within the boundaries of the United States that these men have not yet located or taken into their calculations. Petroleum is widely distributed throughout the world and in sufficient quantities to meet the requirements, present and future, and if the economic law of supply and demand is given a free opportunity to assert itself, artificial, political and governmental restrictions are removed, allowing everybody from everywhere to participate in the prospecting and production necessary, there will be plenty of oil to meet the requirements in all parts of the world for many generations to come.

There are vast areas in all parts of the world that have scarcely been "scratched," which have petroleum deposits equal to the developed areas of the United States. Original development in all countries occurred in the vicinity of indications caused by exudes and seepages through fractures overlying our petroleum deposits. Within the United States in the last few years some of the most important deposits in this country have been discovered, which were not indicated by seepages or otherwise. Important discoveries are continuing to occur in this country and additional discoveries will be made long after the time limit set for exhaustion by some of our experts.

Increased prices have always resulted in increased activity of the wildcatter, which in turn has resulted not only in producing sufficient oil to meet the demands but in bringing about an over-production. There is nothing produced by man anywhere so responsive to the economic laws of supply and demand as petroleum. In the past the activity of the wildcatter within the boundaries of the United States during the period of increased prices has always been sufficient to meet the demands, but the time has arrived when it is necessary and desirable to have a world-wide activity to meet the requirements of the future. This can only be brought about by a change in the attitude of many of the governments of the world, by a change in the numerous restrictive regulations now existing and allowing a free opportunity for everybody from everywhere to participate in the necessary development.

The present shortage has not been caused by any serious exhaustion of the petroleum deposits but has been caused by extraordinary increased consumption. If unrestricted opportunity had continued in Mexico and some of the agitation affecting our public lands of the West in this country had not occurred, there would be no shortage in evidence at the present time. Renewed confidence and activity is now occurring in both countries.

During the war it was necessary to centralize under Government authority and direction all of our resources and while at war this was practical because of the patriotism of the people. All efforts of war are destructive, not only to the enemy but to the resources far removed from the battle front, and a great deal was necessarily undertaken regardless of economic principles or waste. Following the war, the return to private ownership and direction to secure the necessary incentive and re-establish practical economic principles should have been brought about as quickly as possible.

Technical Sessions

Two technical sessions were arranged for in cooperation with the Society for the purpose of bringing the automotive engineers and the oil engineers and chemists into as close professional relations as possible. The committee of the Society which is charged with the duty of making recommendations relating to research work conferred during the meeting, and tests will be formulated and conducted in connection with unsolved internal-combustion engine fuel problems.

F. C. Mock, of the S. A. E. Fuel Committee, prepared for the Conference a statement on the utilization of present automotive fuel. He explained that in the case of the ordinary passenger-car engine the individual fuel charges vary in volume from that of a sphere of about 3/16 in. in diameter, for the full-load charge, to much less with the engine idling. These charges must be delivered in 1/6 sec. at the lowest engine speed, and in 1/100 sec. at very high speed. In three years of intensive research only one method has been found of accomplishing this fuel feed with an accuracy that will give any sort of satisfactory operation. This involves metering the fuel along with and under the same force as the air flow, and delivering the fuel thus metered to the engine either as a vapor or a fine mist, commingled with the air charge. Whatever drawbacks exist in the fuel system of our automotive engines today, they are derived not from this principle but from their failure to

function according to it. Mr. Mock said that experiments by trial have shown that the present fuel will not and cannot possibly atomize at the temperatures and under the conditions of operation of our motor cars. Probably 90 per cent of the cars in use are operating with an intake-manifold temperature below 120 deg. fahr. Under such condition the fuel system fails lamentably. The fuel feeds to the cylinders irregularly and intermittently, and to give operation under the requirements of changing load and speed, it is usually necessary to increase the richness of mixture from 15 to 30 per cent, which is highly detrimental to many functions of the mechanism, as well as a notable economic waste. If the spray from the carbureter is directed upon a surface heated to a temperature near or above the end boiling-point of the fuel, the already fine drops from the carbureter will be broken up into even smaller particles, and it is possible to produce this condition and attain good engine operation at a mixture temperature 40 to 50 deg. fahr. below the temperature of complete vaporization of the fuel.

With fuel of the present end-point, the exhaust temperature is adequate even with the engine idling. If the end-point of the fuel be raised, a point will be reached where the exhaust temperatures at light loads are too low for proper action, and an external application of heat will be necessary. Mr. Mock conceives the future fuel requirements to be, first and most important, stability of fuel characteristics. Troubles encountered with "casinghead" gasoline in warm weather, and blends of "high-test" gas and kerosene in cold weather, are minor instances of the difficulty resulting from the variation in fuel quality; second, the invention and general use of an ingredient that can be added to the present fuel to prevent detonation and to permit more satisfactory operation with present compression, and a development toward higher compression with its resultant gain in fuel economy.

W. F. Parish presented a paper on dilution of crankcase oil, and proposed a new method of determining such dilution. He pointed out that the use of heavy fuels in engines designed for the use of the lighter and more volatile fuels had brought about an unbalanced condition of the fuel, the engine and the lubricating oil, and developed the dilution problem. He stated that with all four-cycle engines some leakage of the fuel mixture takes place during the compression stroke, the amount of leakage depending upon the mechanical fit of the rings and the degree of perfection of the seal formed by the lubricating oil. The gas that escapes has all of the component parts of the fuel mixture in the cylinder at the time of leakage. The gas that leaks into the crankcase is broken up by the eddies of air and oil vapor, and the fuel is absorbed by the lubricating oil. There is no dilution when the engine is operated with natural or artificial gas. In this case the lubricating oil gets heavier. If the heaviest of the distillates is used in the same engine and under the same conditions, the leakages combining with the oil make a mixture of various proportions of lubricant and fuel. Dilution difficulties are more pronounced in winter than in summer. The amount of lubricant that works into the upper parts of the cylinder and is consumed depends upon the body of the lubricant. Thick oil works up very slowly and is naturally consumed more slowly than thin oil. In the same engine, with the same fuel and temperatures, for the same period of time, dilution will be greater with the thinner oil.

Dr. H. C. Dickinson and S. W. Sparrow of the automotive powerplants section of the Bureau of Standards contributed some results of tests bearing on possible fuel savings in automotive engines. They premised that the typical automobile engine, while representing a triumph of engineering as regards simplicity and engineering, leaves much to be desired in the way of fuel economy, stating that under ordinary road conditions the efficiency probably does not exceed 10 per cent; and of this 10 per cent much is lost in transmission to the rear wheels and to the road. They summarized the immediate possibilities of fuel conservation in existing engines as follows:

(1) By avoiding unnecessarily rich mixtures in the operation of all automotive vehicles as at present equipped

(2) By supplying carbureter and manifold equipment on new and, in some cases, on older cars, which will make better fuel economy possible, or in other words cook the engine food according to the dictates of economy

The numerous fuel improvers and dopes of various kinds marketed with guarantees to increase the mileage, remove carbon and generally improve the behavior of engines, are evidence of the results that can be secured in many instances by inducing the driver to use a leaner mixture, as most, if not all, of the various improvers have absolutely no effect other than to induce the user to exercise more care in the use of fuel.

Numerous tests made for the sake of comparing average carbureter settings with the best settings for different cars have shown that without any other changes whatever, fuel consumption can often be reduced as much as 25 per cent. The average driver has his carbureter set much too rich for best operation under average driving conditions. The dash adjustment fitted on most vehicles at present permits the operator to control the mixture ratio at will. While this practice enables the careful operator to save fuel, it also allows the careless driver to waste an excessive amount, and the economy which a careful operator can effect in this respect is important, particularly when a vehicle is often allowed to stand and cool off.

Extreme performance in acceleration necessarily means much waste of fuel, except in the rare cases where the intake manifold is sufficiently heated to supply a substantially dry mixture to the engine.

There is no question whatever that increasing the end-point of fuels increases the fuel consumption in gallons per mile of the average car. This increase in specific consumption certainly becomes very rapid with increasing end-point above about 400 deg. fahr.

There is some evidence to show that in the present average engine fuels the end-points have approached if not passed the point where a further increase will actually deplete rather than increase the total available fuel supply. If engine fuel alone were to be considered, the end-point could be increased to such a point that further increase in end-point would increase the consumption more than it would increase the production.

In opening the technical sessions Mr. Horning gave a comprehensive outline of automotive internal-combustion engine conditions in current practice, including a brief summary of the thermodynamic principles involved, and taking up matters related to thermal and mechanical efficiency, he explained the way in which the brake mean effective pressure of engines depends upon the air cycle, combustion, mechanical and volumetric efficiencies, the density of the fuel charge and a constant factor which he specified. In speaking of the manner in which it is claimed that incorporating the so-called dopes

in petroleum fuel permits an increase of the compression ratio and, in turn, of thermal efficiency, he recommended that the petroleum industry should include in the fuel produced by it more of the aromatics or homologues.

There was considerable discussion of oil viscosity as affecting an engine's mechanical efficiency and, in consequence, the thermal efficiency. An important problem in connection with the efficient utilization of fuel is securing adequate vaporization, it being advocated that the lightest lubricating oil possible under the prevailing conditions in a given instance should be used. The inclusion of free fatty acids in lubricating oil, which has been discussed recently in connection with the so-called germ process, was mentioned. Various matters relating to piston design and clearances were taken up.

The improved utilization of kerosene, which the farm tractor industry has developed, was emphasized. The load on tractor engines being a maximum for a large part of the time, kerosene can be used as fuel for them better than for passenger cars, where the engine loads fluctuate greatly and are light during a large part of the time. For a similar reason heavier fuel can be used in motor trucks more satisfactorily than in passenger cars.

Proper End-Point

The most important feature of the meeting from a technical standpoint was the discussion of the proper end-point for gasoline for automobiles. It was argued by Mr. Crane that it is impossible to build into an automotive engine to be used widely by the public non-adjustable devices that will burn the present gasoline as efficiently as it should be burned. On many cars the heavy end-points of gasoline go into the combustion-chamber in a liquid and not in a vapor or a fog form. Under these conditions it is impossible to combine air with the fuel in proper proportion constantly; the heavier portion of the fuel cannot be taken care of by the carbureter. The public wants good car acceleration, and this can be had only with a richer mixture than is most economical. It is felt by the automotive engineers that a considerable percentage of the gasoline currently produced is not only waste material inasmuch as it is not burned in the engine, but produces crankcase oil dilution, engine carbonization and other objectionable conditions.

Mr. Crane said that it is very doubtful whether any portion of a petroleum fuel having a distillation temperature above 400 deg. fahr. is of actual value in an automotive engine for general use in the hands of the public, the dividing line, of course, depending on the type of service. It is expected that comprehensive scientific tests will be made to determine this question, which is now largely a matter of opinion. With reference to the economic use of gasoline by motor-car users, it is thought that improvement in this respect is principally dependent upon educational movements and better service conditions.

To secure a greater thermal efficiency of automobile engines, higher compression pressures than are currently used are necessary, and it is apparent that to this end modification of the gasoline currently produced is essential. The volatility of the present fuel should be exhaustively investigated, and it is believed that the oil chemists and the automotive engineers will proceed aggressively in this connection, each group supplementing the efforts of the other by research work. The matter of the widespread use of small economical cars is inexplicably involved in the public demand. It is very questionable whether the time will ever come when the American public will be satisfied to shift gears frequently enough to secure full-load engine conditions and resultant economy.

The representatives of the oil industry stated that they receive less complaint from automobile users now with regard to gasoline than they did several years ago when 350-deg. end-point gasoline was to be had. The automotive engineers feel that the currently produced 437-deg. end-point fuel has never been demonstrated by scientific tests to be the most economical automotive engine fuel that can be made available to the public under present conditions.

There was considerable argument at the meeting with regard to the reason for the decreased use of motor cars in winter, that is the extent to which this is attributable to difficulty in engine starting in cold weather. The starting trouble can be ascribed partly to the fuel and partly to the lack of adequate auxiliary engine apparatus. Undue carbureter choking results in maintenance difficulties such as crankcase oil dilution, dirty valves and engine carbonization.

It is believed that the very beneficial cooperation that has been inaugurated within the last year between the American Petroleum Institute, the Society of Automotive Engineers and the National Automobile Chamber of Commerce, will be extended in scope and effectiveness, resulting in frequent interchange of information between automotive engineers and oil chemists, and the authoritative determination of the most economical automotive engine fuel end-point for both summer and winter service.

BIG MARINE DIESEL ENGINE

THE following table gives the principal dimensions and specifications of the recently produced 2400-hp. Worthington marine Diesel engine.

Indicated horsepower	2,400
Brake horsepower	1,750
Mean effect of pressure, lb. per sq. in.	85.5
Mechanical efficiency, per cent	75
Bore, in.	29
Stroke, in.	46
Compression, lb.	500
Injection pressure, lb.	900
Main bearings, in.	17½ x 24
Crankpins, in.	15 x 18
Wrist pins, in.	9½ x 10½
Length, ft.	55½
Height, ft.	23¾
Weight of crankshaft, tons	36½
Weight of engine, tons	339¼
Weight per indicated horsepower, lb.	327

According to a recent issue of *Power* from which this information is taken, this is the largest four-cycle marine Diesel engine that has been built thus far.

PETROLEUM INDUSTRY

THE time may be foreseen when, through the accomplishments of technochemical investigation, the petroleum industry will yield a range of fuels for the internal-combustion engine only; kerosene in quantity narrowing to that desirable for country use and export trade; lubricating oils adjusted to the growing demands of mechanical power; and an ever-widening range of chemical products supporting a great petroleum by-products industry, rivaling if not exceeding the coal-products industry in importance. In respect to the last, it should be emphasized that the United States today faces an opportunity similar to that which 20 years ago confronted both Germany and the United States as regards the manufacture of dyestuffs, explosives, fertilizers, drugs and other chemicals from the non-fuel components of coal.—W. A. Hamor.

Naval Architecture in Aeronautics[1]

By COM. J. C. HUNSAKER, U. S. N.[2] *Illustrated with* DRAWINGS

AN attempt is made in the accompanying charts to give a graphical analysis of the weights of heavier-than-air craft from a purely empirical standpoint and to establish the trend of design, if any definite trend does exist. Some of the charts give negative results but, in my opinion, are still useful to explode certain theories as to the effect of mere size on performance.

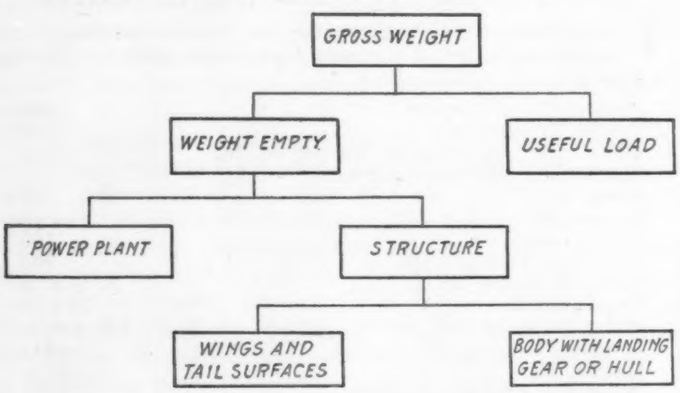
For the purpose of this study, the following classification is used:

(1) Single-seater airplanes
(2) Two-seater airplanes (1 to 3½ tons gross)
(3) Multi-engined airplanes (3½ to 9 tons gross)
(4) Multi-engined airplanes (9 tons and over)

Within each class there are three subdivisions into (*a*) land planes, (*b*) float seaplanes and (*c*) boat seaplanes.

The three principal variables affecting the performance of an airplane are gross weight, pounds per horsepower and pounds per square foot, and these items are, therefore, considered to be fundamental, and variation of other items considered with respect to them.

The weight of an airplane is divided into its main groups in accordance with the following scheme:



To make the body group comparable in all types of machine, there are included in it in the case of land airplanes, the fuselage and landing gear; in the case of float seaplanes, the fuselage, floats and their struts; and in the case of boat seaplanes the hull and auxiliary floats. In order that the body weights of various types of boat seaplane may be comparable, any outriggers which support the tail are included in the body group. The powerplant group includes machinery with all accessories and tanks. The useful load includes fuel, crew and military load.

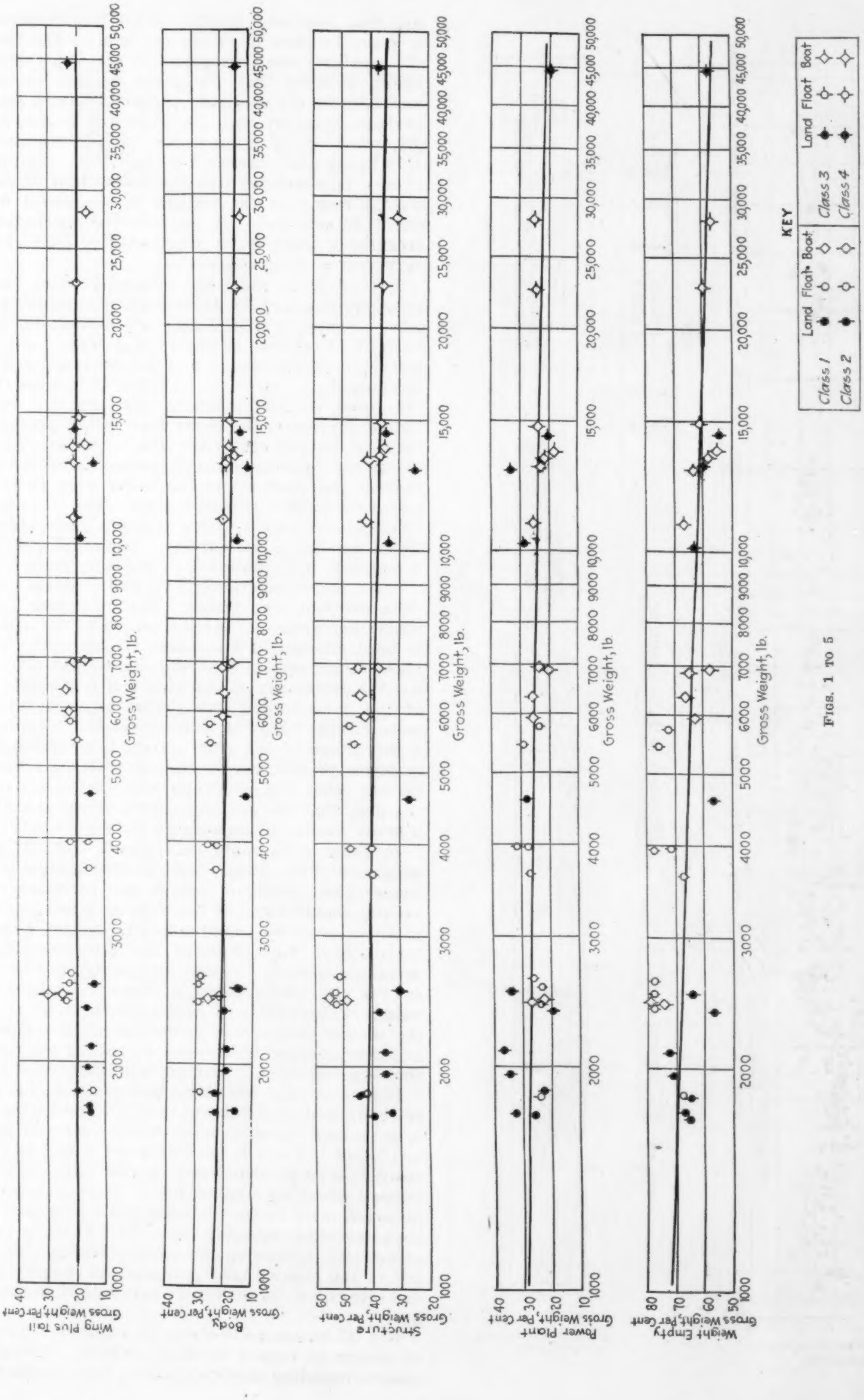
Fig. 1 shows the wing and tail weight expressed as a percentage of the gross weight plotted against the gross weight. A representative line drawn through the points indicates a uniform weight of 20 per cent of the gross. The points lie remarkably close to this line, and in general the points which lie above have a higher factor of safety or a lighter loading than the ones below. The large machines, it should be remembered, have generally higher wing loadings and reduced factors of safety. The United States Navy training seaplanes may be noted in a group above the line at 2500 lb. These machines have a light wing loading and a high factor of safety. At about 3800 lb. and below the line is located the Curtiss HA float seaplane, which has a high wing loading and a moderate factor of safety. The Curtiss HS boat seaplanes are in the vicinity of 6000 lb. and very near the line. The same may be said of the F5 group at about 13,000 lb. and the NC group at about 25,000 lb.

Fig. 2 gives the body weight in percentage of the gross weight. A representative line drawn through this group of points appears to have a downward slope. It will be noted that up to about 6000 lb. the seaplanes lie considerably above the line, while above 6000 lb. the seaplanes lie very near the line. Almost invariably the land planes lie below the line, indicating that the body weight of seaplanes is greater than that of corresponding land machines except in the very largest sizes. In large flying boats the hull, combining the functions of landing gear and fuselage, weighs about the same as the corresponding group of the airplane.

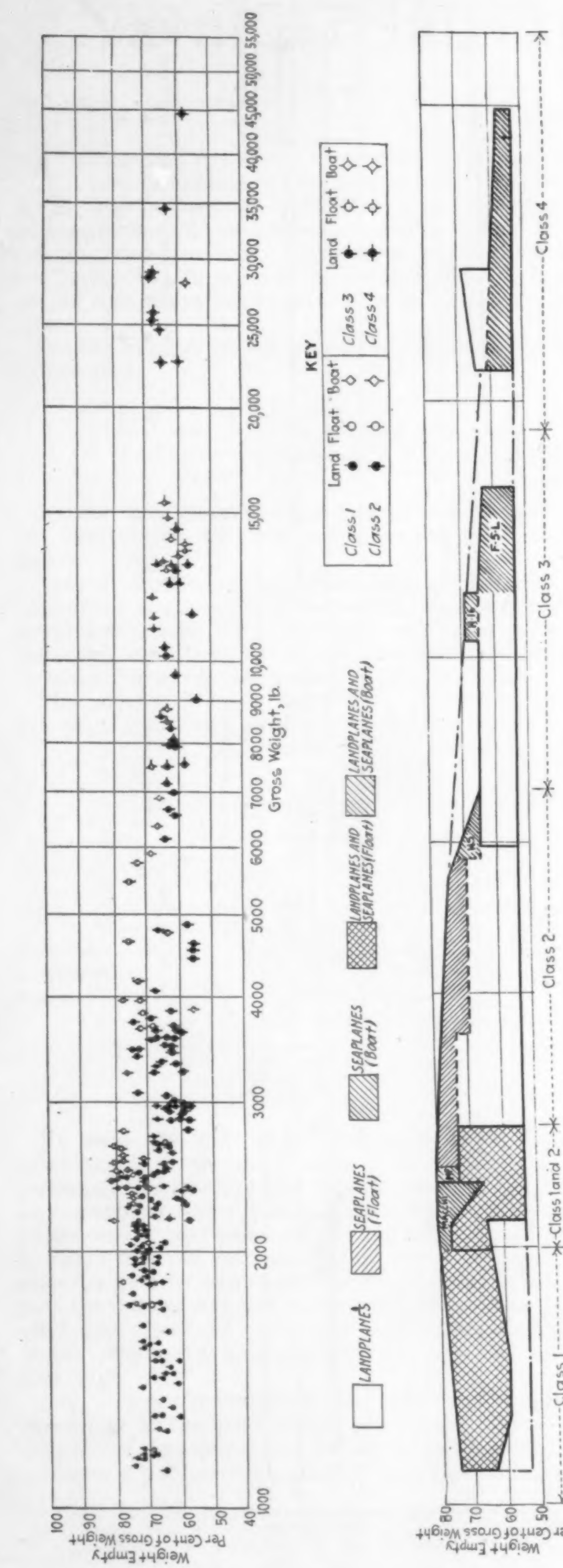
It is more difficult to find a representative line for Fig. 3, which is a plot of the structural weight obtained by a summation of the ordinates of Figs. 1 and 2. The different types are, however, segregated in a logical manner. The training machines, about 2500 lb., have a high percentage of structural weight as expected. The seaplanes and flying boats up to approximately 7000 lb. have a noticeably higher structural weight than the corresponding land machines. Fig. 4 is a plot of powerplant weight with a mean line showing a downward trend, indicating that as size increases the percentage of powerplant weight decreases. This seems reasonable, as the large machines are not designed for great speed and the power is more nearly in proportion to gross weight than in the smaller machines which are generally considerably over-powered. Fig. 5 is a plot of weight empty or structure plus powerplant. The mean line drawn through the points indicates that as the size increases the percentage useful load increases, but only slightly.

To throw more light on this most important indication of a trend in design, Fig. 6 has been prepared to include similar data for some 200 machines of all types. It is confirmed by this more comprehensive chart that, as before, the weight empty in percentage of the gross weight decreases slightly with the size, leaving a larger percentage of useful load. There is a distinct trend established, but the most interesting feature is the insignificance of the advantage of mere size. This chart was examined to discover any segregation by types. Such segregation is shown graphically in Fig. 7. where the heavy outlines represent the classes. It will be noted that the single-seat machines of Class 1 and the two-seaters of Class 2 overlap between 2000 and 2700 lb. It was impossible to distinguish between the land planes

[1]Wilbur Wright memorial lecture delivered before the Royal Aeronautical Society of Great Britain at London, June 22, 1920. Reprinted in abstract form through the courtesy of the Royal Aeronautical Society.
[2]Bureau of Construction and Repair, Navy Department, Washington.


Wing Plus Tail Gross Weight, Per Cent
Body Gross Weight, Per Cent
Structure Gross Weight, Per Cent
Power Plant Gross Weight, Per Cent
Weight Empty Gross Weight, Per Cent
Gross Weight, lb.
KEY
Land Float Boat
Class 1
Class 2
Class 3
Class 4

Figs. 1 to 5



FIGS. 6 AND 7

and float seaplanes in Class 1, but boat seaplanes are in a group by themselves. In the case of the two seaters all seaplanes are segregated in the upper part of the chart, showing that for gross weights between 2000 and 7000 lb. the seaplanes appear to have a smaller percentage of useful load. In Class 3 it is shown how the F5, which is an improvement and development of the H16 flying boat, carries a greater load. To summarize, it may be concluded that the lower limit of percentage weight empty so far realized by successful designs is about 53 per cent. It may also be concluded that in large sizes there is no superiority of land planes over seaplanes as weight carriers.

Figs. 8 to 11 show the relation between these same group weights and the power loading or pounds per horsepower. There is a large range of loading, but the points lie thickest between 12 and 18 lb. per hp., the high-speed airplanes lying below 12 and the low-speed and training machines lying above 18. In Fig. 8 it appears that as the power loading increases, the per cent powerplant weight decreases, the lower limit being practically constant at 20 per cent from 15 lb. per hp. up. Fig. 9 brings out a rise in percentage structure with high power loading, due probably to the larger wing surface necessary on account of reduced speed. The large percentage of structural weight in the training plane region, 22 to 26 lb. per hp., is noteworthy. Considering Figs. 8 and 9 together, it is evident that seaplanes have, in general, a lower percentage powerplant and a higher percentage structure than land planes. This, of course, indicates a poorer performance. As the weight of the wing surface is most affected by the power and generally represents about 50 per cent of the structural weight, Fig. 10 showing the percentage of the wing and tail weight in terms of the gross weight was plotted to show this increase more clearly. Fig. 11 which gives the weight empty as a percentage of the gross weight is interesting, in that it seems to indicate, neglecting training airplanes and certain other abnormal airplanes in the upper part of the plot, that the minimum light weight is obtained for a power loading of between 14 to 18 lb.

In general, it would be expected that, if the group weights of Figs. 8 to 11 were plotted against pounds per square foot instead of pounds per horsepower, the envelopes should slope in the reverse direction. Figs. 12 to 15 on page 508 confirm this contention although not conclusively. Fig. 12 shows that the per cent structure decreases with an increase of loading, and is supported by Fig. 13, which shows a decrease of wing and tail weight with increase of wing loading. Fig. 14, in which the weight empty as a percentage of the gross weight is plotted against the loading in pounds per square foot shows, as expected, a decrease with high wing loading.

Fig. 16 on page 509 shows how designers have selected the wing loading for machines of different sizes. There is no marked segregation between seaplanes or land planes in Classes 1, 2 and 3, but in Class 4 it will be noted that the boat-type seaplanes have higher wing loadings than the corresponding land machines. The wing loading is determined more by the allowable maximum landing speed than any other consideration. This chart is principally of interest in showing the upward tendency of the loading in the case of boat seaplanes as the size increases, and brings out the principal advantage of the large flying boat.

Fig. 17 on page 509 shows in a general way the trend of design in regard to wing weights. The unit wing weight, including struts and wires, but excluding tail sur-


Power Plant-Gross Weight, Per Cent
Structure-Gross Weight, Per Cent
Wing Plus Tail-Gross Weight, Per Cent
Weight Empty-Gross Weight, Per Cent
Lb. per Hp.
KEY
Land Float Boat
Class 1
Class 2
Class 3
Class 4

FIGS. 8 TO 11

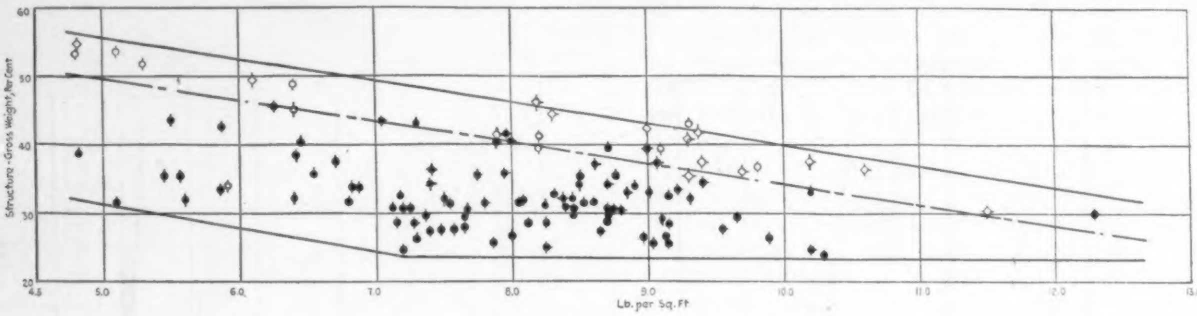


FIG. 12

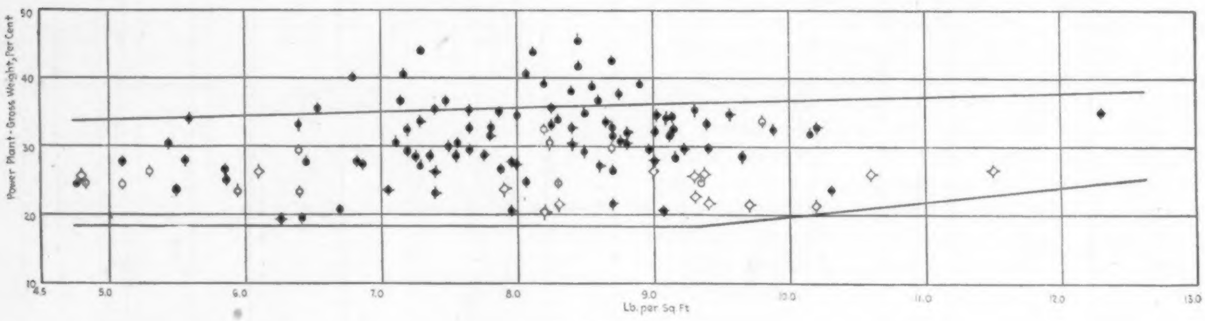


FIG. 13

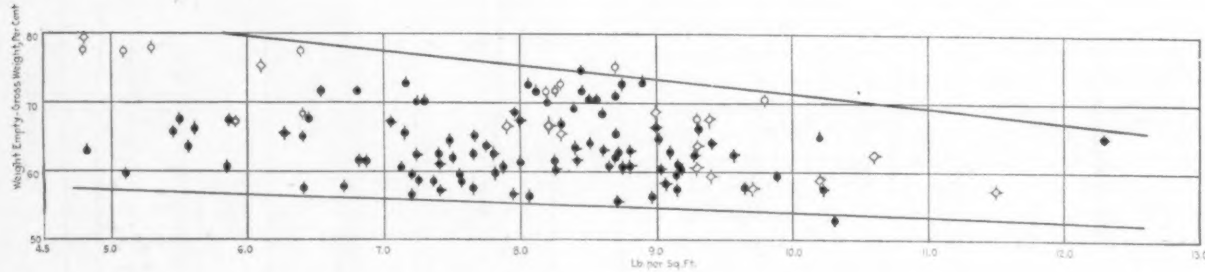


FIG. 14

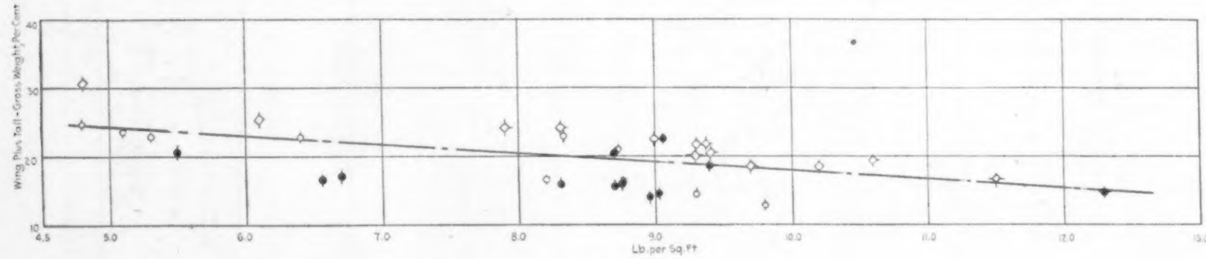
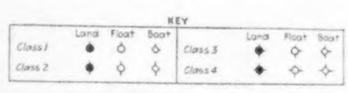


FIG. 15



faces, increased rapidly with wing area up to about 1300 sq. ft., but about this point we have a decrease in factor of safety and the introduction of hollow struts and spars. Probably for these reasons, the unit wing weight does not continue to increase and for especially refined designs may even take a drop. Again at about 2500 sq. ft. we expect the introduction of latticed construction for wing beams and ribs, and again a check in the rising trend of unit wing weights. As a result the unit weight of wings for large machines need not increase materially provided the type of construction is changed to take advantage of opportunities for more economical use of material. In particular, the very large machines, if given a triplane wing arrangement, should show a reduction in unit wing weight, especially where latticed metal construction is introduced.

The symbols in the first column of Tables 1 to 4 denote the class and type of each airplane in accordance with the scheme outlined on page 504. The data in these tables were obtained from official publications of the

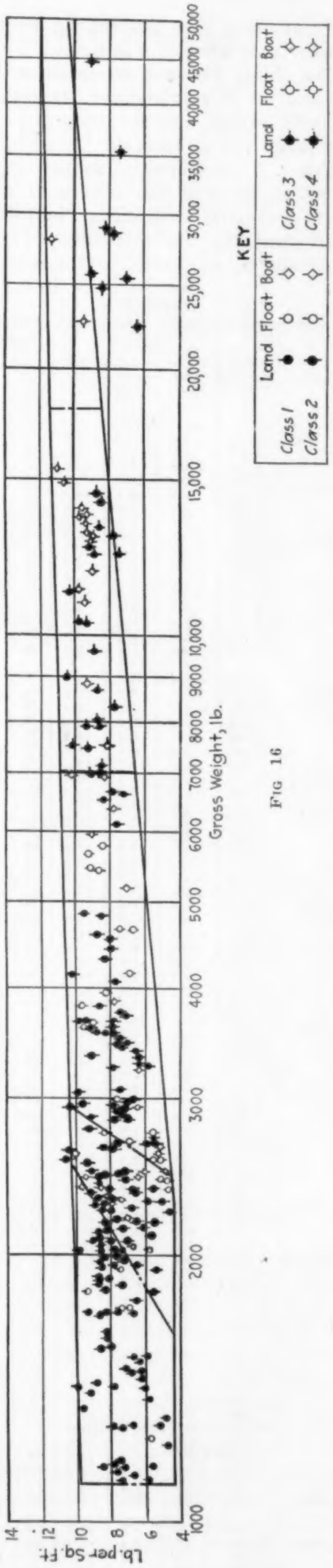

Lb. per Sq. Ft.
Gross Weight, lb.
KEY
Land Float Boat
Class 1
Class 2
Class 3
Class 4

FIG 16

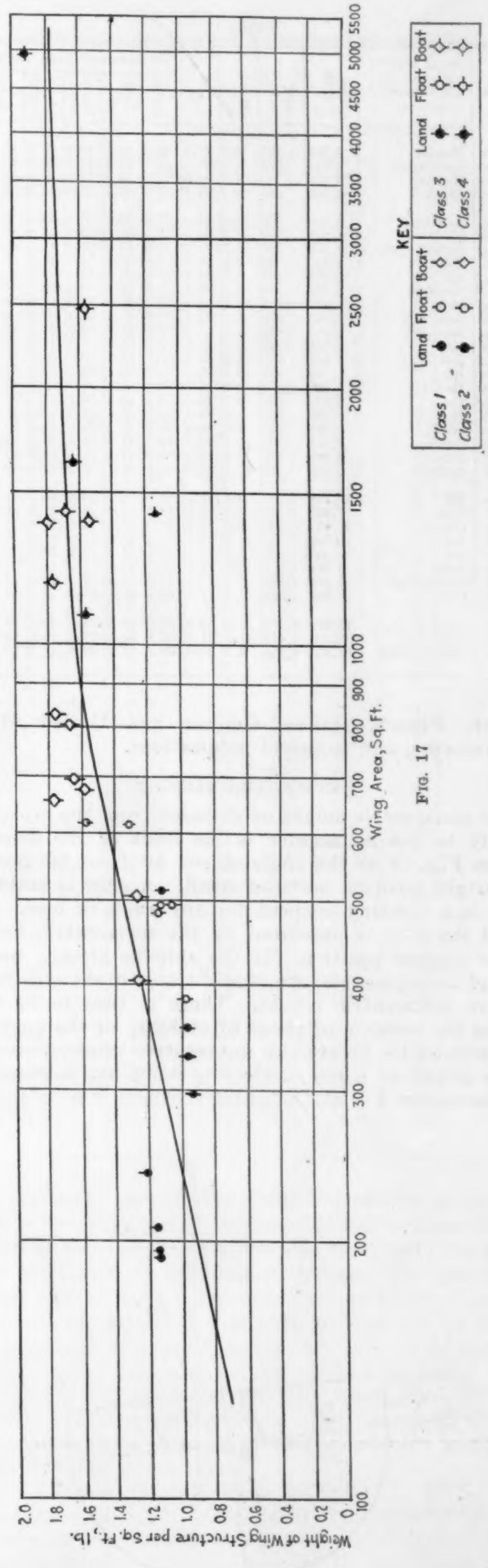

Weight of Wing Structure per Sq. Ft., lb.
Wing Area, Sq. Ft.
KEY
Land Float Boat
Class 1
Class 2
Class 3
Class 4

FIG. 17

TABLE 1

Class	Name	Gross Weight, lb.	Area, sq. ft.	Lb. per sq. ft.	Lb. per hp.	Percentage of Gross Weight				
						Empty	Structure	Power-plant	Wing and tail	Body.
1a	Hanriot	1,709	195	8.7	13.1	65.6	39.0	26.6	15.5	23.5
1a	Avro Spider	1,734	208	8.3	15.1	66.2	32.4	33.8	15.9	16.5
1b	Hanriot	1,827	195	9.3	14.0	67.9	43.0	24.9	14.5	28.5
1a	SE-5A	2,100	240	8.7	11.7	72.9	35.1	37.8	15.7	19.4
2a	Avro 504K	1,829	330	5.5	16.6	67.3	43.8	23.5	20.1	23.7
2a	VE-7	1,958	299	6.5	13.0	71.4	35.7	35.7	16.6	19.1
2a	Sopwith (1½)	2,377	353	6.7	18.2	57.8	37.1	20.7	17.0	20.1
2b	N-9	2,412	496	4.8	24.1	77.9	53.2	24.7	24.5	28.7
2c	MF	2,448	401	6.1	24.4	75.6	49.5	26.1	25.3	24.2
2c	Model 40	2,461	508	4.8	24.6	79.6	54.4	25.2	30.3	24.1
2a	M-8	2,517	204	12.3	8.4	65.0	30.0	35.0	14.9	15.1
2b	Aero, 39B	2,543	494	5.1	25.4	77.6	53.3	24.3	23.6	29.7
2b	Aero, 39A	2,618	494	5.3	26.1	78.0	51.7	26.3	22.9	28.8
2b	HA	3,805	386	9.8	10.0	70.4	36.9	33.5	12.7	24.2
2b	R-6	3,964	613	6.4	19.8	77.7	48.5	29.2	22.6	25.9
2b	H²A	3,975	485	8.2	10.5	71.7	39.6	32.1	16.4	23.2
2a	US D9	4,600	514	9.0	11.5	56.2	26.6	29.6	14.0	12.6
2b	D-4	5,418	620	8.7	14.3	75.2	45.5	29.7	20.6	24.9
2b	M-1	5,795	695	8.3	16.1	72.9	48.4	24.5	23.0	25.4
2c	HS-1L	5,902	653	9.0	16.4	68.9	42.4	26.5	22.3	20.1
2c	HS-2L	6,373	803	7.9	17.7	66.9	41.9	25.0	23.3	18.6
2c	HS-3	6,900	824	8.3	19.1	65.9	44.8	21.1	23.9	20.9
2c	Sperry	6,916	678	10.2	17.3	58.9	37.7	21.2	18.4	19.3
3a	MBT	10,168	1,080	9.4	12.7	64.0	34.2	29.8	18.7	15.5
3c	H-16	10,900	1,164	9.4	15.1	67.9	41.9	26.0	21.4	20.5
3a	Caproni	12,810	1,420	9.0	11.8	60.2	25.7	34.5	14.4	11.3
3c	F-5-L	13,000	1,397	9.3	18.1	63.6	40.8	22.8	21.4	19.4
3c	F-3	13,400	1,425	9.4	19.1	59.1	37.2	21.9	20.5	16.7
3c	F-6-L	13,514	1,397	9.7	18.8	57.4	36.0	21.4	18.4	17.6
3a	Handley Page	14,374	1,648	8.7	17.9	55.6	34.4	21.2	20.3	14.1
3c	F-5-L	14,844	1,397	10.6	17.6	62.3	36.4	25.9	19.4	17.0
4c	NC-2	22,600	2,441	9.3	20.9	60.6	35.5	25.1	20.0	15.5
4c	NC-4	28,000	2,441	11.5	17.5	57.1	30.5	26.6	16.1	14.4
4a	Tarrant Tabor	44,862	4,950	9.1	15.0	58.2	37.6	20.6	22.6	15.0

British, French, Italian, German and United States Governments, and technical publications.

METACENTRIC HEIGHT

The metacentric height or distance from the center of gravity to the metacenter is the limit of the distance *Gm* on Fig. 18 as the angle of roll $\Delta\theta$ from the normal or upright position becomes small. A ship is stable if there is a righting moment for any angle of heel. The initial stability is measured by the metacentric height in the upright position. If the ship be already heeled through a large angle, she is still stable if she still has a positive metacentric height. There is thus to be considered the problem of range of stability or the angle of heel permissible before the metacentric height vanishes.

The period of a roll, neglecting damping, is given by the expression $t = \pi k / \sqrt{(g.Gm)}$, where k is radius of gyration. It appears that the rolling will be quick and hence uncomfortable when *Gm* is large. For an easy ship *Gm* should be small, but not so small as to impair the range of stability. For passenger steamers *Gm* may be made small with safety, but for warships it is necessary to provide a large *Gm* to provide for stability in a damaged condition. I have spoken so far of the "lateral" metacenter which controls the rolling of vessels. There is, of course, a strictly analogous "longitudinal" metacenter which controls the pitching. The metacentric height is, of course, an index to the statical condition

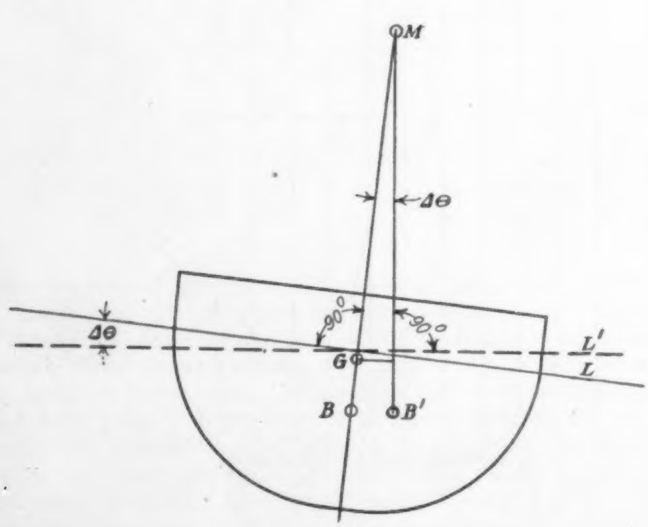


FIG. 18

TABLE 2

Class	Name	Gross Weight, lb.	Area, sq. ft.	Lb. per sq. ft.	Lb. per hp.	Percentage of Gross Weight		
						Empty	Structure	Power-plant
1a	Nieuport XXI	1,179	161	7.3	14.7	70.0	43.0	27.0
1a	Da	1,275	180	7.1	13.4	60.2	30.1	30.1
1a	Db	1,400	153	9.2	14.7	60.9	32.7	28.2
1a	Morane A1	1,429	140	10.2	8.4	65.0	33.0	32.0
1a	Dc	1,720	254	6.8	12.3	71.4	31.4	40.0
1a	Dd	1,855	254	7.3	11.2	70.0	26.0	44.0
1a	De	1,865	221	8.5	11.0	74.9	29.8	45.1
1a	Spad XIII	1,887	226	8.3	8.6	70.0	31.0	39.0
1a	Df	1,960	225	8.7	11.8	71.0	28.6	42.4
1a	Dg	1,990	278	7.2	12.0	72.8	32.4	40.4
1a	Dh	2,000	247	8.1	12.0	71.7	28.2	43.5
1a	Di	2,020	239	8.5	12.3	71.7	30.3	41.4
1a	Albatros	2,037	226	8.9	12.5	73.0	34.0	39.0
1a	Dk	2,101	246	8.6	12.7	70.3	31.5	38.8
1a	Dl	2,260	280	8.1	12.2	72.3	31.8	40.5
1a	Albatross	2,425	288	8.4	8.2	69.0	31.0	38.0
2b	Sopwith-1	2,041	344	5.9	15.2	57.0	34.0	23.0
2b	F B A Type C	2,070	322	6.4	15.9	68.0	45.0	23.0
2a	Ba	2,300	449	5.1	16.4	59.7	31.8	27.9
2b	Spad	2,335	282	8.3	10.6	72.0	41.0	31.0
2a	Ca	2,361	258	9.1	14.2	59.6	25.5	34.1
2a	Bb	2,390	438	5.5	21.6	65.7	35.5	30.2
2a	Cb	2,498	348	7.2	14.4	65.2	28.7	36.5
2a	Hanriot	2,507	274	9.1	9.7	63.0	29.0	34.0
2a	Bc	2,680	457	5.9	21.6	67.4	42.4	25.0
2a	Ar Type L	2,756	484	5.6	13.4	66.0	32.0	34.0
2a	Cc	2,775	297	9.1	16.7	57.8	26.4	31.4
2a	Cd	2,840	370	7.7	17.4	57.4	28.0	29.4
2a	Ce	2,870	397	7.2	17.6	59.4	30.2	29.2
2a	Spad XX	2,877	312	9.0	9.0	65.0	33.0	32.0
2a	Cf	2,900	384	7.6	17.5	59.6	31.1	28.5
2a	Cg	2,920	402	7.3	17.6	58.9	30.4	28.5
2a	Ch	2,945	388	7.6	17.1	58.2	27.6	30.6
2a	Salmson 2	2,956	388	7.6	11.0	62.0	32.0	30.0
2a	Ci	2,970	411	7.2	17.2	56.6	24.3	32.3
2a	Ck	2,970	308	9.7	17.9	57.9	29.3	28.6
2a	Cl	2,980	438	6.8	17.9	61.7	33.9	27.8
2a	Cm	2,990	405	7.4	18.0	58.4	29.8	28.6
2a	Cn	3,000	435	6.9	18.1	61.2	33.8	27.4
2a	Co	3,260	415	7.8	14.5	59.9	27.4	32.5
2a	Breguet 14 A	3,344	527	6.4	11.9	65.0	32.0	33.0
2a	Cp	3,360	367	9.2	15.0	60.7	28.3	32.4
2a	Sea	3,400	398	8.6	8.8	65.0	30.0	35.0
2a	Cq	3,415	461	7.4	14.7	62.5	27.2	35.3
2a	Cr	3,450	450	7.7	15.4	62.4	29.6	32.8
2a	Cs	3,500	466	7.5	15.2	64.1	27.7	36.4
2a	Ct	3,575	433	8.3	15.9	61.4	28.4	33.0
2a	Cu	3,580	414	8.7	15.5	62.2	30.8	31.4
2a	Cv	3,620	460	7.9	13.5	60.8	25.8	35.0
2a	Cw	3,630	366	9.9	13.5	59.4	26.2	33.2
2a	Le Pere	3,655	393	9.3	10.1	67.0	32.0	35.0
2a	Cx	3,680	460	8.0	13.7	61.1	26.6	34.5
2b	DD	3,750	568	6.8	18.8	63.0	44.0	19.0
2a	Cy	3,820	438	8.7	14.5	62.3	29.4	32.9
2a	Breguet	4,090	527	7.7	10.1	65.0	30.0	35.0
2a	Ja	4,150	400	10.3	18.5	51.8	24.0	27.8
2a	Jb	4,430	546	8.1	19.7	56.4	31.7	24.7
2a	Caudron R-11	4,839	538	8.5	11.5	64.0	35.0	29.0
2a	Ga	6,150	792	7.8	18.6	63.9	35.5	28.4
2a	Gb	6,560	797	8.3	14.2	60.5	25.0	35.5
2a	Gc	6,670	915	7.3	12.2	62.1	28.5	33.6
2a	Gd	6,700	849	7.9	20.5	66.9	40.1	26.8
2a	Ge	7,000	809	8.7	15.6	60.9	27.6	33.3
3a	Gf	7,180	853	8.4	16.0	63.3	30.9	32.4
3a	Gg	7,500	816	9.2	16.7	63.0	33.5	29.5
3a	Gh	7,540	740	10.2	14.1	57.6	24.7	32.9
3c	Tellier	7,600	928	8.2	19.0	67.0	47.0	20.0
3a	Gi	7,980	835	9.6	14.9	62.4	27.9	34.5
3a	Gk	7,980	915	8.7	14.9	60.6	30.2	30.4
3a	Gl	8,050	915	8.8	15.0	61.0	30.8	30.2
3a	Gm	8,370	1,072	7.8	15.6	62.5	31.3	31.2
3a	Caproni	8,752	1,023	8.8	16.3	63.0	33.0	30.0
3a	Voisin E 87	12,566	1,679	7.4	15.7	57.0	34.0	23.0
3a	Handley Page	13,360	1,539	8.6	18.7	64.0	37.0	27.0
4a	Ra	22,600	3,570	6.3	30.7	65.1	45.5	19.6
4a	Handley Page	24,989	2,992	8.4	17.9	62.0	32.0	30.0
4a	Rb	25,300	3,570	7.1	23.6	67.0	43.2	23.8
4a	Rc	25,800	2,860	9.0	24.0	66.6	39.5	27.1
4a	Rd	28,600	3,570	8.0	23.2	68.9	41.3	27.6
4a	Re	28,800	3,570	8.1	23.4	67.3	40.1	27.2
4a	S. Schukert	35,274	4,789	7.4	19.8	62.0	36.0	26.0

TABLE 3

Class	Name	Gross Weight, lb.	Area, sq. ft.	Lb. per sq. ft.	Lb. per hp.	Weight Empty in Terms of Gross Weight, per cent
1a	Macchi M 16A	562	122	4.60	5.90	62.6
1a	Macchi M 16G	562	122	4.60	7.90	60.6
1a	SA-2	810	156	5.20	14.70	64.2
1a	Ordnance E-C	1,117	190	5.90	13.90	74.8
1a	Macchi M-14	1,135	172	6.60	12.70	73.8
1a	Standard E-1	1,144	153	7.50	14.30	72.4
1a	Gabardini	1,150	160	7.20	12.80	71.1
1a	Macchi Mi 13	1,150	140	8.20	12.80	69.2
1a	Morane S-3OEZ	1,157	145	7.80	8.50	77.1
1a	Morane S-3OEv	1,157	145	7.80	12.30	77.1
1a	Bristol Scout	1,159	204	5.70	14.50	68.1
1a	Nieuport 24	1,210	161	7.50	9.30	65.0
1a	Sopwith Pup	1,225	254	4.80	14.60	64.2
1b	Beards NlA	1,238	219	5.70	14.80	66.7
1a	Macchi Ni	1,270	...	7.90	10.50	68.6
1a	Macchi HD	1,270	...	6.90	10.50	66.9
1a	Sopwith Pup	1,297	252	5.20	12.40	66.0
1a	Morse S4-C	1,373	235	5.90	17.20	71.1
1a	Macchi M14	1,412	...	7.90	11.80	68.8
1a	Sopwith Camel	1,422	231	6.20	10.40	62.5
1a	Nieuport 24	1,442	145	9.90	8.50	64.0
1a	Sopwith Camel	1,453	231	6.30	11.60	63.9
1a	Sopwith Camel	1,471	231	6.40	9.80	65.4
1a	Vickers FB-19	1,478	211	7.00	11.60	60.5
1a	DH-5	1,492	211	7.10	11.80	67.5
1a	Sopwith Camel	1,523	233	6.60	10.20	63.5
1a	Sopwith Triplane	1,543	257	6.00	12.40	71.3
1a	Spad 7-Cl	1,553	194	8.10	9.10	70.9
1a	Spad 18	1,560	194	8.10	9.10	71.0
1a	Nieuport 28	1,563	181	8.40	8.80	66.8
1a	Hanriot	1,605	195	8.30	12.30	63.6
1a	Spad	1,632	200	8.20	10.90	71.7
1b	Sopwith Camel	1,721	231	7.50	13.70	68.0
1b	Sopwith Baby	1,742	245	7.10	13.90	73.3
1a	Sopwith Snipe	1,775	270	6.60	7.80	74.0
1a	Spad 13 C	1,820	224	8.50	8.30	69.2
1b	Hamble Baby	1,946	256	7.60	17.10	71.3
1a	Spad CA1	1,947	222	8.60	9.20	66.4
1a	Ansaldo A1	1,950	...	8.60	8.90	72.3
1a	Se-5A	1,958	247	7.90	9.30	71.5
1a	Vickers MVT	1,970	231	8.50	8.90	73.0
1a	SE-5	1,980	249	8.00	9.80	73.5
1a	Sopwith Dolphin	2,000	262	7.70	9.50	69.5
1a	Sopwith Snipe	2,020	270	7.50	8.90	65.4
1a	Morse MB-3	2,037	250	8.20	6.00	64.3
1a	Spad 17Cl	2,077	222	9.10	6.90	73.0
1a	BE-12	2,104	371	5.70	13.20	73.0
1a	Ansaldo SVA-4	2,130	260	8.20	9.70	71.5
1a	Ansaldo SVA-6	2,150	260	8.30	9.80	71.8
1c	Macchi PB	2,183	313	7.00	13.60	80.1
1a	Salmson	2,264	258	8.60	9.00	67.7
1a	Martinsyde F-4	2,269	330	7.00	7.50	75.4
1a	Sopwith Snipe	2,271	269	8.90	10.00	58.5
1c	Macchi M-5	2,280	...	8.10	12.00	73.7
1c	Macchi M-5	2,300	...	7.30	12.10	74.0
1a	Spad 21	2,309	253	8.90	7.30	73.1
1a	Sopwith Bomber	2,342	350	6.70	18.80	56.0
1c	Macchi M-7	2,380	...	8.50	9.60	69.8
1b	Ansaldo 1SVA	2,385	...	9.70	11.60	79.4
1c	Macchi AS	2,390	...	8.60	12.60	70.0
1b	Ansaldo 1SVA	2,430	...	9.20	11.90	79.6
1a	Martinsyde F-3	2,446	338	7.20	8.50	76.0
1a	Martinsyde	2,458	410	6.00	14.50	73.0
1a	Martinsyde Cl	2,465	332	7.40	7.80	69.5
1a	Nieuport Cl	2,532	266	9.50	7.30	70.4
1a	Ansaldo A-5	2,620	322	8.10	9.10	66.1
1a	Spad H-20-Cl	2,660	312	8.30	8.40	63.4
2a	Macchi Ni 18	1,371	194	7.10	15.20	69.5
2a	Caudron AER	1,610	290	5.50	17.90	61.0
2a	JN-4D	1,920	353	5.40	21.30	74.5
2a	Vickers-Terni	1,965	602	3.30	20.60	72.0
2a	Ansaldo SVA2	2,030	236	8.60	10.00	75.5
2a	Vickers-Terni	2,060	602	3.40	18.70	63.5
2a	VE-7	2,090	292	7.20	11.60	72.2
2a	Vickers-Terni	2,100	602	3.50	18.30	67.0
2a	Ansaldo SVA9	2,130	289	7.40	10.50	71.5
2a	JN-4H	2,145	353	6.10	14.30	74.4
2a	VE-7 G	2,200	292	7.50	12.20	68.6
2a	Aeromarine	2,220	494	4.50	22.20	74.3
2a	VE-7-GF	2,300	292	7.90	12.80	69.6
2a	Ansaldo SVA10	2,390	289	8.20	10.80	67.5
2b	Boeing	2,455	495	5.00	24.60	79.0
2a	Ansaldo SVA10	2,460	289	8.40	9.90	68.5
2c	Model F	2,460	387	6.40	24.60	75.6
2b	N-9	2,550	488	5.20	17.00	80.0
2b	Type LS	2,570	251	10.20	8.60	70.6
2b	N-9 (Mod.)	2,663	490	5.50	17.70	80.1
2a	JN-6 HB	2,687	353	7.60	19.90	66.9
2b	Tyne AS	2,695	386	7.00	9.00	66.3
2b	N-9	2,750	496	5.50	18.30	77.8
2a	Sit Voisin	2,760	580	4.70	14.50	72.0
2c	SIA-S13	2,840	370	7.60	11.30	69.1
2a	Bristol USB-2	2,848	406	7.00	9.80	63.0
2a	Bristol	2,910	403	7.20	9.70	63.3
2c	Macchi L-3	2,980	495	6.00	15.70	66.7
2c	Macchi L-3	2,980	495	6.00	15.10	66.5
2a	Bristol USXB	2,994	406	7.40	10.00	67.1
2c	SIA-S8	3,010	495	6.10	13.70	65.0
2a	SAML-S2	3,080	420	7.35	11.80	73.0
2c	Zari FBA	3,100	450	6.90	16.30	66.0
2a	SAML 6	3,140	485	6.50	12.10	70.3
2c	SIA-S8	3,157	495	6.40	16.60	66.7
2c	Macchi M-8	3,170	430	7.30	16.60	68.5
2c	SIA-FBA	3,220	452	7.10	16.90	67.5
2c	SIA-S8	3,220	495	6.50	16.10	68.0
2c	Tellier	3,225	506	6.40	16.10	76.6
2a	R-4	3,272	545	6.00	16.40	68.0
2a	Savi Sp-2	3,360	720	5.20	14.40	73.6
2a	Pomilio PE	3,400	495	6.85	11.30	73.8
2a	Ansaldo A300	3,460	...	.....	11.56	73.0
2a	Pomilio PD	3,480	495	7.10	13.40	74.6
2a	DH-4	3,582	440	8.10	10.00	66.7
2b	HA	3,680	387	9.50	9.70	72.8
2a	SIA-R2	3,710	500	7.40	12.40	74.5
2a	SIA-SP3	3,730	645	5.80	14.40	73.4
2a	Breguet	3,750	526	7.10	12.50	68.2
2c	SIAI-S9	3,840	512	7.50	12.80	68.3
2c	DD	3,860	491	7.90	19.30	56.6
2c	Macchi M-9	3,880	495	7.80	12.90	68.5
2b	R-9	4,184	613	6.80	20.90	72.9
2a	USD-9A	4,322	514	8.40	12.00	65.1
2a	Pomilio VL-12	4,540	580	8.00	11.70	56.4
2b	R-6-L	4,634	613	7.60	12.90	75.8
2b	D-9	4,670	718	6.50	12.30	63.7
2a	USD-9A	4,872	514	9.50	13.50	57.8
2c	Levi Le Pen	5,180	739	7.00	18.50	58.9
2c	SIAI-S12	5,210	562	9.30	10.90	66.2
2b	R-6-L	5,662	613	9.30	15.70	62.1
2a	Caproni CA 2	6,460	1,045	6.10	19.50	66.0
2a	Caproni CA 2	6,710	1,045	6.30	16.00	66.5
2a	SIA-BR	7,000	756	9.20	16.20	68.2
3c	TF	8,846	930	9.50	14.80	63.0
3a	DH-10A	9,000	851	10.60	12.50	53.9
3a	Martin Bomber	9,663	1,070	9.00	14.40	60.7
3a	MT	11,148	1,070	10.40	14.00	52.2
3c	H-16-1	11,168	1,124	9.90	15.50	66.2
3c	H-16-2	11,875	1,306	9.10	18.00	68.9
3c	F-5-L	15,430	1,397	11.10	21.50	63.2
3c	Bast. PRB	16,150	2,155	7.50	16.10	59.0

only, but for all practical purposes has served the naval architect very well.

Unfortunately, the airplane designer has not 100 years of experience to draw on and there has been no ready handle on an airplane to seize upon like a metacentric height. Consequently, a great deal must be left to judgment, artistic feeling, comparison with other airplanes, and eventually to the opinon or prejudice of the test pilot. The need for some ready means for off-hand judgment of airplane stability and maneuverability has been felt for a long time. The mathematics of stability are too cumbersome for practical use, and require extensive wind-tunnel research to establish the necessary constants. It is my experience that we can build and fly a small airplane in less time than it takes to perform the stability calculations.

The general case of the disturbed motion of an airplane is not simple, but the longitudinal or symmetrical motion is two-dimensional and can be considered apart from the lateral or asymmetric motion. For the longitudinal motion, we are interested in the pitching oscillations and the criterion that such oscillations be stable. For airplanes of normal design, if there be a righting moment called into play by any angular deviation from the normal attitude,[3] the pitching oscillations so produced are strongly damped. In other words, if an airplane be statically stable it is also dynamically stable, so far as pitching is concerned.[4]

My colleague, Com. William McEntee, U. S. N., suggested the application of the naval architect's metacenter to measure the statical stiffness of an airplane's longitudinal stability. I have assembled the data from all of the wind-tunnel tests on complete model airplanes that I had available, and have computed the metacentric height

[3]A positive value of M_w in Bairstow's notation.

[4]Hunsaker, "Dynamical Stability of Aeroplanes," Smithsonian Miscellaneous Collection, vol. LXII, No. 5.

TABLE 4

Class	Name	Gross Weight, lb.	Area, sq. ft.	Lb. per sq. ft.	Unit Weight of Wings, lb. per sq. ft.
1a	Hanriot	1,700	195	8.7	1.15
1a	Avro Spider	1,734	208	8.3	1.17
1b	Hanriot	1,827	195	9.3	1.15
1a	SE-5 A	2,100	240	8.7	1.22
2a	Avro 504 K	1,820	330	5.5	0.98
2a	VE-7	1,958	299	6.5	0.95
2a	Sopwith (1½)	2,377	353	6.7	0.97
2b	N-9	2,412	496	4.8	1.06
2c	MF	2,448	401	6.1	1.27
2c	Model 40	2,461	508	4.8	1.30
2b	Aero. 39 B	2,543	494	5.1	1.09
2b	Aero. 39 A	2,618	494	5.3	1.09
2b	HA	3,805	386	9.8	0.99
2b	R-6	3,964	613	6.4	1.32
2b	HA	3,975	485	8.2	1.14
2a	US D-9	4,600	514	9.0	1.13
2b	D-4	5,418	620	8.7	1.50
2b	N-1	5,795	695	8.3	1.63
2c	HS-1-L	5,902	653	9.0	1.78
2c	HS-2-L	6,373	803	7.9	1.69
2c	HS-3	6,900	824	8.3	1.76
2c	Sperry	6,916	678	10.2	1.60
3a	MBT	10,168	1,080	9.4	1.59
3c	H-16	10,900	1,164	9.4	1.76
3a	Caproni	12,810	1,420	9.0	1.15
3c	F-5-L	13,000	1,397	9.3	1.81
3c	F-3	13,400	1,425	9.4	1.70
3c	F-6-L	13,514	1,397	9.7	1.55
3a	Handley Page	14,374	1,648	8.7	1.66
3c	F-5-L	14,844	1,397	10.6	1.81
4c	NC-2	22,600	2,441	9.3	1.59
4c	NC-4	28,000	2,441	11.5	1.50
4a	Tarrant Tabor	44,862	4,950	9.1	1.93

from the observed slope of the curve of pitching moments in the following manner:

$\triangle M/\triangle\theta =$ slope of curve of pitching moment

But $M = (\triangle M/\triangle\theta)\theta$

And $M = WGm \sin\theta = WGm\theta$, for small angles

Then $Gm = (1/W)\ (\triangle M/\triangle\theta)$

This algebraic definition of Gm has the dimensions of a length and amounts to from 2 to 12 ft. for modern airplanes and flying boats. It is directly proportional to the coefficient M_w of Bairstow's notation, but immensely more easy to remember for use for purposes of comparison. It is also proportional to the center of pressure motion. To give the length Gm a physical meaning, Fig. 19 has been drawn to an exaggerated scale. It will be

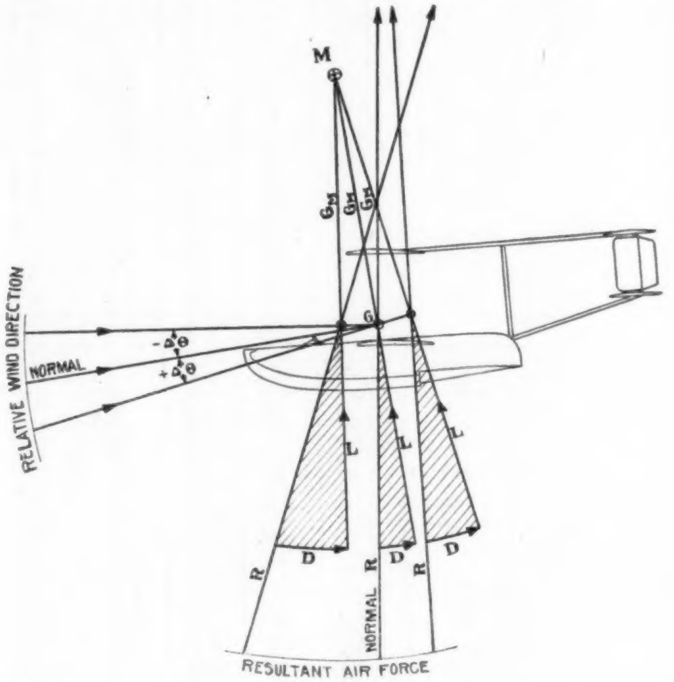


FIG. 19

noted that m is the intersection of resultant lift vectors for successive angles of incidence, resolving the lift component at a line of reference through the center of gravity in the direction of motion. As an intersection, m is, therefore, dependent on the angle of incidence, and

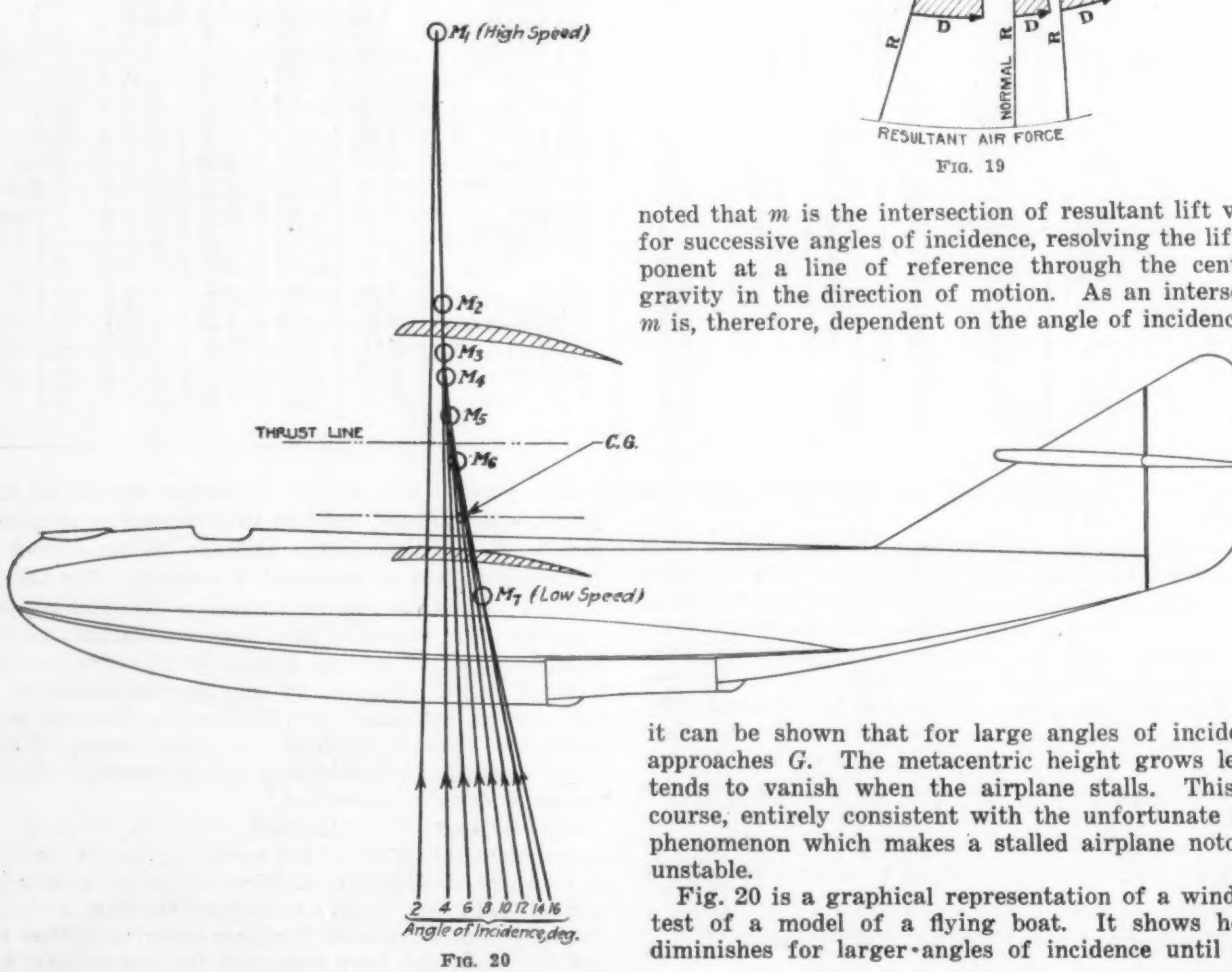


FIG. 20

it can be shown that for large angles of incidence m approaches G. The metacentric height grows less and tends to vanish when the airplane stalls. This is, of course, entirely consistent with the unfortunate natural phenomenon which makes a stalled airplane notoriously unstable.

Fig. 20 is a graphical representation of a wind-tunnel test of a model of a flying boat. It shows how Gm diminishes for larger angles of incidence until it van-

TABLE 5

Machine	Weight, lb.	Chord, ft.	Angle of Stabilizer to Wing, deg.	Angle of Attack, deg.	Gm, ft.
SA-2	625	6.00	−2.00	9	3.35
Morane-Saulnier	1,210	5.50	—	12	3.17
AEG-D1	1,275	4.50	+0.25	4	5.00
Boeing 2	1,600	5.00	−2.20	6	4.87
Farman (1912)	1,610	6.10	—	10	6.78
Curtiss JN-2	1,800	5.00	−3.50	2	9.35
SVA	1,985	5.25	−2.50	5	5.72
Boeing 1	2,000	5.60	−5.00	6	13.45
Thomas-Morse SH4	2,300	5.60	−5.00	6	8.66
Curtiss N-9	2,310	5.00	−2.00	6	2.80
Sturtevant S4	2,650	7.00	−5.00	4	7.45
Bristol Fighter	2,680	5.50	−1.75	3	8.03
Burgess S	2,800	6.50	−3.50	8	5.02
Le Pere Fighter	3,655	5.50	−0.10	2	3.15
USD-9A Bomber	4,320	6.00	−2.80	6	12.61
N-1 (USN)	5,500	6.75	−4.00	8	6.00
Curtiss HS-1L	5,500	6.30	−5.50	9	7.18
Curtiss H-12	8,050	7.00	−3.00	8	12.90
TF (USN)	8,850	9.00	−2.00	10	10.77
F-5-L	13,500	12.00	−1.50	9	6.80
Handley Page	14,425	10.00	−1.50	6	11.95
NC-1	22,000	12.00	−2.00	8	11.20
NC-TA	28,000	12.00	−1.00	8	27.40
TB (USN)	60,000	22.00	−5.50	8	22.20
Verville-VCPI	2,425	5.50	−0.50	4	3.84
Le Pere-USAP2	2,100	4.50	−1.00	8	4.00
Triplane-GAX	9,450	6.00	−0.90	6	2.30

ishes at about 12 deg. Table 5 gives the metacentric heights calculated from wind-tunnel tests on complete models without propellers of 27 types. Airplanes both small and large are included, as well as float seaplanes and flying boats. We have a truly miscellaneous collection, with British, French, German and American examples, which should give a good test of the naval architect's method of classification by means of metacentric height. Designers have, in general, been giving a greater metacentric height for great chord length, which appears reasonable. Plotting the metacentric height against chord length on Fig. 21 brings this out clearly. The points group themselves about a straight line. It therefore seems possible from a knowledge of the relation of chord to metacentric height for any design to say with some confidence whether the machine will be more or less stable longitudinally than the average, and whether such stability will be reasonable or abnormal.

Effect of Change in Angle of Stabilizer Setting and Area

In Table 6 are assembled calculations of *Gm* from wind-tunnel tests in which the setting of the stabilizer has been altered. To bring out the effect of such changes, Fig. 22 on page 514 has been made where *Gm* is plotted against the angle of stabilizer setting, i. e., the angle between the stabilizer and the wing chord. It will be noted that the points fall near straight lines whose slopes are the change in *Gm* per degree change in angle of stabilizer setting. This slope is denoted by $\Delta Gm/\Delta\beta$ and is plotted against the ratio of horizontal tail area to wing area in Fig. 23 (see page 514). It is found that $\Delta Gm/\Delta\beta$ depends on the area of the horizontal tail surfaces in a straight-line function. The slope of each line of Fig. 22 when plotted on Fig. 23 falls near either one or the other of two straight lines which have substantially the same slope. It is to be noted from these lines that the tractor type tail surface is less efficient than the NC, a pusher-type tail surface, a conclusion consistent with previous experimental work.

The values of *Gm* for changes in stabilizer area are given for various machines in Table 7 on page 514. These values when plotted against percentage of the original area (see Fig. 24 on page 514) lie near straight lines.

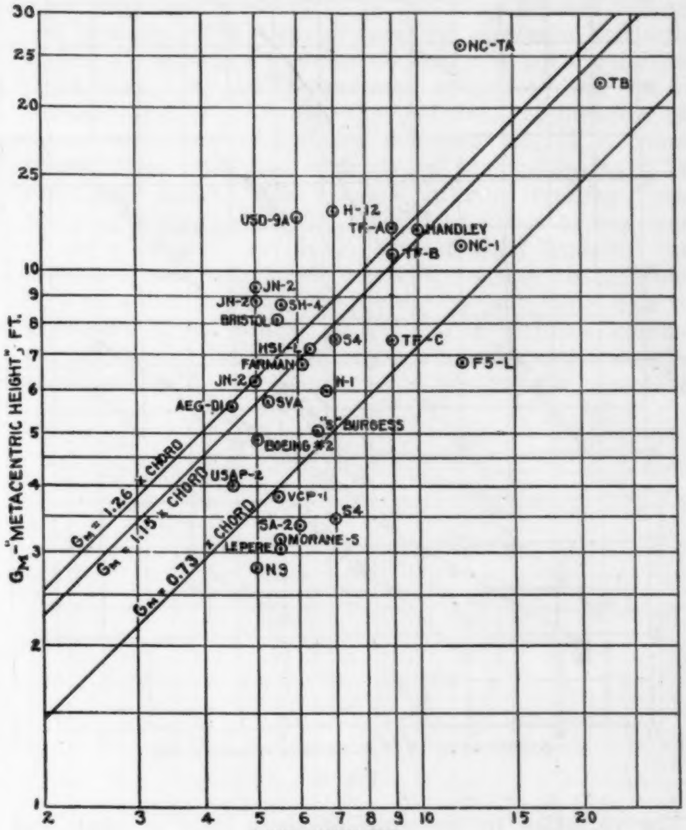


Fig. 21

TABLE 6

Machine	Angle between Stabilizer and Wing Chord, β, deg.	Gm, ft.	$\frac{\Delta Gm}{\Delta\beta}$	Horizontal Tail Surface in Terms of Wing Area, per cent
S4	−3.20	3.44	2.20	12.60
S4	−5.00	7.45		12.60
JN-2	−3.50	6.21		10.38
JN-2[6]	−5.00	8.44	1.45	10.38
JN-2	−7.00	11.14		10.38
JN-2[5]	−2.00	5.80		11.52
JN-2[6]	−3.50	9.34	1.85	11.52
JN-2	−5.00	11.55		11.52
JN-2[6]	−1.00	6.21		12.66
JN-2[7]	−2.00	8.00	2.40	12.66
JN-2	−3.50	12.43		12.66
Le Pere	−1.00	9.17		12.90
Le Pere	0.00	6.76		12.90
Le Pere	+1.10	3.13	2.35	12.90
Le Pere	+2.10	2.15		12.90
Le Pere	+3.00	0.00		12.90
Verville	+0.50	2.63		12.20
VCPI	0.00	3.09	1.80	12.20
VCPI	−0.50	3.84		12.20
VCPI	−1.00	5.27		12.20
USAP2	+0.50	3.21		No
USAP2	−0.50	2.98	1.35	data
USAP2	−1.00	4.00		
USAP2	−1.50	4.30		
NC-1[8]	−3.00	14.35	3.30	13.10
NC-1	−1.00	7.61		13.10
NC-1[9]	−3.00	7.45	2.50	11.13
NC-1	−1.00	2.30		11.13
NC-1[10]	−3.00	5.31	22.90	10.72
NC-1	−1.00	1.43		10.72
Bristol Fighter	+0.25	1.43		10.80
Bristol Fighter	−1.75	4.75	1.35	10.80
Bristol Fighter	−3.50	6.15		10.80

[5]Small tail, medium body.
[6]Medium tail, medium body.
[7]Large tail, medium body.
[8]Curtiss tests with large tail.
[9]Curtiss tests with medium tail.
[10]Curtiss tests with small tail.

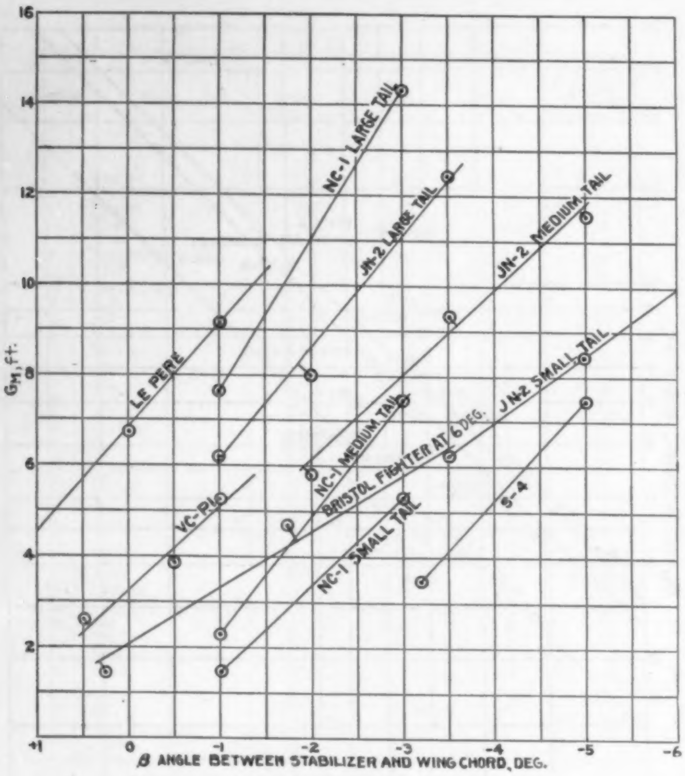


FIG. 22

The variation in the slope of these lines is small and seems to be independent of the original size of the stabilizer.

Fore-and-Aft Movement of Center of Pressure

To study the movement of the center of pressure, the 4-deg. vector location, or line of action of total air force for an angle of incidence of 4 deg., has been determined for a number of machines and for various stabilizer settings. These locations, which may be found in Table 8, are plotted on Fig. 25. For each machine the points are found to lie near a straight line, the line for the larger machines having, however, a greater slope than those for the smaller machines. In Fig. 26 the slopes from the lines of Fig. 25 are plotted against the wing chord of the machines which they represent. The fact that all of the points so plotted lie very nearly on a straight line indicates that the movement of the 4-deg. vector with any change in the angle of stabilizer setting is almost entirely dependent upon the wing chord. The

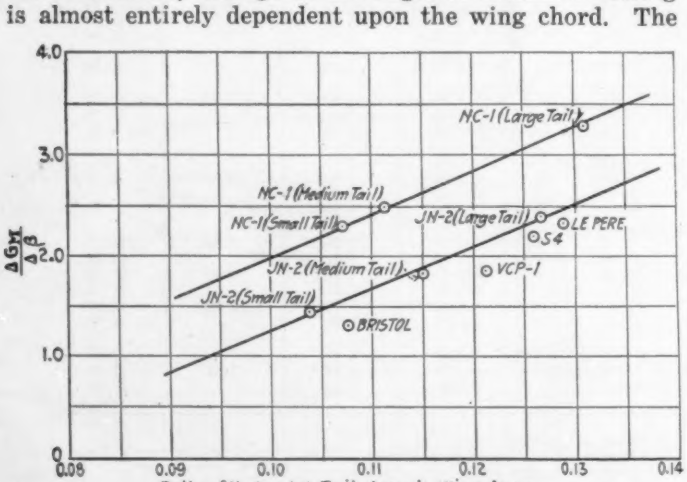


FIG. 23

average value of the movement of the 4-deg. vector per degree change in stabilizer setting is found to be 0.033 × chord. This movement is forward if the normally negative angle between stabilizer and wing chord is increased, and vice-versa.

In the foregoing discussion I have tried to bring out the fact that an airplane actually has a metacentric height which is entirely under the control of the designer. It would clarify our knowledge of airplanes very much if we knew the initial metacentric height the designer gave it. Knowing this, we could judge with some degree of confidence whether the machine is reasonably stable for its type. Further, if we knew the metacentric height as designed, the effect of stabilizer adjustment could be considered more intelligently than it is at present. The adjustable stabilizer is a very useful and convenient device for altering the balance of a machine, but it also alters the metacentric height. It is quite possible by excessive use of this means to balance up an otherwise tail-heavy machine, entirely destroying the metacentric height and hence the stability. The tables and charts I have given here will prove useful, I trust, in the consideration of such a possibility for a particular design.

Determination of Control Surface Areas

Ships' rudders are made large or small depending on the maneuverability required. The exact size of rudder to use for any design of vessel is determined from an

TABLE 7

Machine	Horizontal Tail Area in Terms of Original Area, per cent	s/S	Gm	Remarks
JN-2	90	10.38	6.24	N.A.C.A. Report 17.
JN-2	100	11.52	9.55	Stabilizer at—3.5 deg. to wing chord.
JN-2	110	12.66	12.00	$\Delta Gm/\Delta(s/S)=0.29$.
NC-1	100	13.00	8.61	U.S.N.—W.T.R. 56.
NC-1	114	14.83	14.33	Stabilizer at—4 deg. to wing chord. $\Delta Gm/\Delta(s/S)=0.39$.
NC-1	100	13.10	14.35	Curtiss tests.
NC-1	85	11.13	7.45	Stabilizer at—3 deg. to wing chord
NC-1	81	10.72	5.31	$\Delta Gm/\Delta(s/S)=0.46$.
NC-1	100	13.10	7.61	Curtiss tests
NC-1	85	11.13	2.30	Stabilizer at—1 deg. to wing chord.
NC-1	81	10.72	1.43	$\Delta Gm/\Delta(s/S)=0.31$.
N1	100	15.42	7.17	U.S.N.—W.T.R. 49.
N1	107	16.60	9.00	Stabilizer at—4 deg. to wing chord. $\Delta Gm/\Delta(s/S)=0.31$.

analysis of the rudder areas used on other vessels of similar type. Although a considerable literature has been built up dealing with the theory of turning, the naval architect for a new design still depends on experience. But this experience has been carefully analyzed in the light of existing theory and made available for immediate application in the form of empirical rules and coefficients. In a similar manner the maneuverability of airships and airplanes has been investigated experimentally by full-scale and model tests, and by analysis based on theoretical mechanics. The results give a theory of a qualitative nature which may be useful as a guide, but the designer must in the end risk his reputation on his judgment and experience. He cannot predict with confidence the proper sizes to give the rudders, elevators and ailerons of a new design from purely theoretical considerations.

To make the application of experience in new work

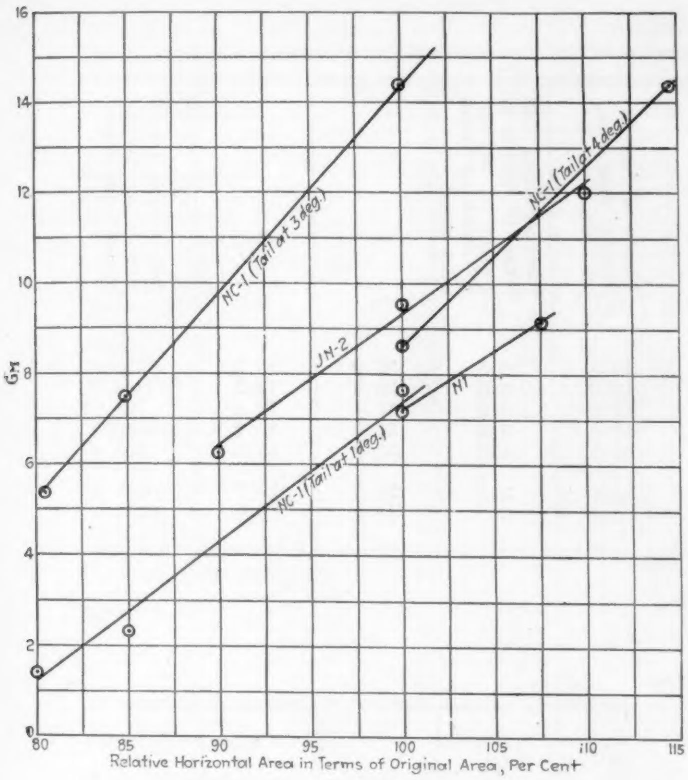


Fig. 24

more direct, I have attempted here to apply the naval architect's method to data assembled for a large number of successful aircraft and to establish empirical rules and coefficients for the design of the control surfaces. To make this possible, the various machines under review are grouped by types into classes and, naturally, the coefficients found apply only to machines of these general

TABLE 8

Machine	Vector, deg.	Stabilizer Setting, β, deg.	Vector Location, ft.	Movement, L, ft.	Wing Chord, ft.	$\Delta L/\Delta\beta$
Le Pere	4	−1.00	6.15	−0.24		
Le Pere	4	0.00	6.39	0.00	5.5	0.170
Le Pere	4	+1.10	6.53	+0.14		
Le Pere	4	+2.00	6.67	+0.28		
Bristol Fighter	4	+0.25	6.32	0.00		
Bristol Fighter	4	−1.75	5.92	−0.40	5.5	0.245
Bristol Fighter	4	−3.30	5.44	−0.88		
USD-9A	4	−1.00	7.40	0.00		
USD-9A	4	−2.80	7.06	−0.34	6.0	0.165
USD-9A	4	−4.50	6.50	−0.56		
VCPI	4	+0.50	—	—		
VCPI	4	0.00	2.94	0.00	5.5	
VCPI	4	−0.50	2.87	−0.07		0.230
VCPI	4	−1.00	2.68	−0.26		
Handley Page	4	+2.20	1.92	+0.93		
Handley Page	4	+1.00	1.38	+0.39		
Handley Page	4	0.00	0.99	0.00	10.0	0.370
Handley Page	4	−1.00	0.62	−0.37		
Handley Page	4	−2.00	0.24	−0.75		
Handley Page	4	−3.00	−0.04	−1.03		
JN-2	4	−3.50	0.67	0.00		
JN-2	4	−5.00	0.75	−0.08	5.0	0.090
JN-2	4	−7.00	1.00	−0.32		
JN-2	4	−2.00	0.42	0.00		
JN-2	4	−3.50	0.67	−0.25	5.0	0.130
JN-2	4	−5.00	0.75	−0.33		
JN-2	4	−1.00	0.33	0.00		
JN-2	4	−2.00	0.42	−0.09	5.0	0.135
JN-2	4	−3.50	0.67	−0.34		
NC-1	4	−1.00	0.75	0.00	12.0	0.450
NC-1	4	−3.00	1.65	−0.90		
USAP2	4	+0.50	0.13	0.00		
USAP2	4	−0.50	0.23	−0.10	4.5	0.170
USAP2	4	−1.00	0.37	−0.24		
USAP2	4	−1.50	0.43	−0.30		
TB	6	−5.50	0.00	−3.05		
TB	6	−2.50	1.95	−1.10	22.0	0.650
TB	6	−1.50	2.60	−0.45		
TB	6	−0.50	3.05	—		

types with control surfaces of the same general shapes and location. The various types of airplanes and seaplanes are arranged in seven classes, and I will consider these first. My own experience indicates that, for a normal type of machine, the judicious application of these coefficients will insure a normal degree of maneuverability. Machines with radical innovations must be considered apart. For example, ailerons trailing from the rear margin of a wing should be about 11 per cent of the wing area for flying boats of usual type, but the Curtiss F boat with interplane ailerons required ailerons of area equal to nearly 18 per cent of the wing area to give reasonable lateral control. The airplane control surfaces under consideration are the horizontal stabilizer combined with the elevator, the vertical fin combined

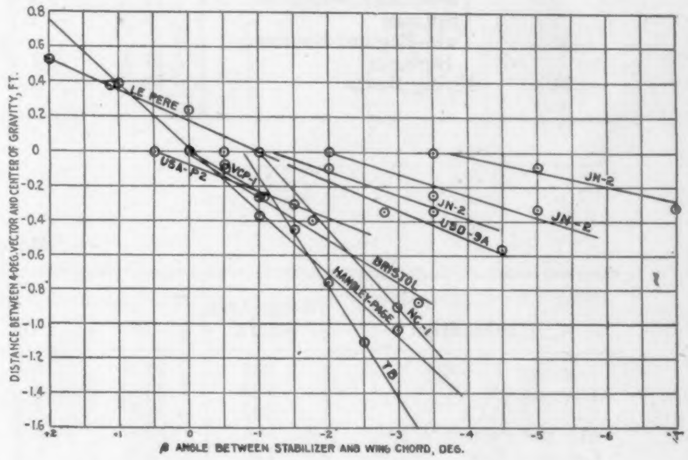


Fig. 25

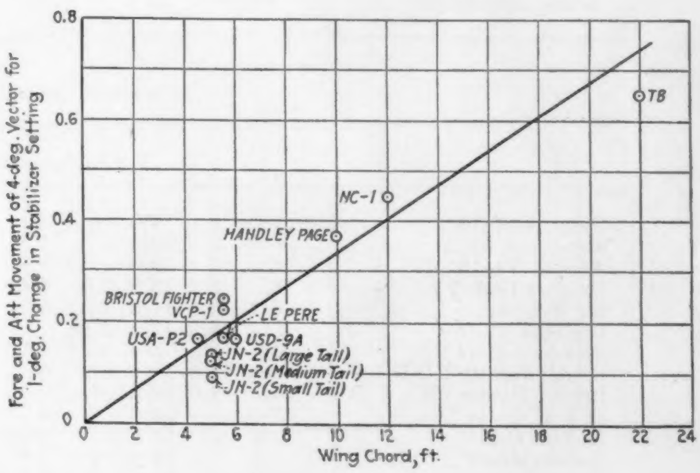


Fig. 26

with the rudder, and the ailerons. No attempt has been made to separate the elevator from the stabilizer or the fin from the rudder; the gross areas only of the combinations are listed.

Tail Surfaces and Ailerons

The necessary horizontal tail surface should depend on the pitching radius of gyration and the degree of maneuverability which are roughly fixed by the procedure of classification by types. Also, the center of pressure motion between high and low-speed attitudes or the depth of chord and the length of the tail must be important variables. These are also fixed in classification by types,

TABLE 9

SUMMARY

Number in Class	Class	Horizontal tail surfaces in terms of wing area, per cent (h)	Vertical tail surfaces in terms of wing area, per cent (v)	Aileron surface in terms of wing area, per cent (a)	Distance from tail hinge to center of gravity of airplane in terms of mean wing chord (t)	(th)	(tv)	Aspect ratio (maximum span divided by maximum chord)
8	Monoplanes	14.8	6.1	12.5	2.5	37.0	15.2	5.0
20	Single-Seater	11.8	4.4	12.9	3.0	36.4	13.2	5.9
17	Two-Seater Non-Training	11.7	4.3	12.6	3.2	37.4	13.8	7.3
4	Two-Seater Seaplanes	11.4	4.0	11.3	3.3	37.6	13.2	8.7
7	Triplanes	9.2	3.7	11.2	4.0	36.8	14.8	9.6
12	Twin-Engined Bombing Biplanes	11.1	4.2	11.3	3.5	38.8	14.7	9.2
11	Flying Boats	13.8	6.3	11.2	3.0	41.4	18.9	10.4

Monoplanes

Designation	Wing Area sq. ft.	(h)	(v)	(a)	(t)			Aspect Ratio
Loening (M-8-0)	251	15.0	6.7	11.6	2.9			4.4
Loening (M-8)	224	15.2	8.0	16.8	3.0			4.8
Gourdou 2-Cl	202	13.8	5.0	11.7	2.3			4.8
Morane Parasol A R	194	10.0	4.6	11.7	2.7			5.9
Gourdou C-1	177	6.9	7.6	11.3	2.3			4.8
Junker All Metal	158	19.1	5.1	12.9	2.5			4.9
Morane Parasol 27	145	14.3	5.4	11.6	2.2			5.3
Bristol Monoplane	140	24.1	6.6	12.4	2.4			5.2

Two-Seater Non-Training

Breguet 16 BR 2	783	8.4	4.0	13.0	2.9			7.0
Salmson 4 AB-2	675	10.4	4.8	12.8	3.0			7.6
Pomilio VL-12	580	10.3	3.5	8.0	3.6			8.1
Breguet 14-A 2	527	10.2	4.6	12.1	2.9			7.2
De H-4	514	14.2	4.4	16.0	3.5			7.8
USD-9A	514	11.5	4.3	14.8	3.5			7.9
Vickers F-B-14	427	12.4	4.9	13.0	2.9			6.3
Bristol Fighter F-2 B	406	12.0	4.1	12.8	3.1			7.1
Bristol Fighter US	403	10.8	4.1	14.0	3.1			7.1
SEA 4C-2	395	10.0	4.5	11.1	3.2			7.1
Le Pere C-11	391	12.8	4.2	14.3	2.9			7.1
Hannoveraner	360	14.2	3.6	9.1	3.2			7.7
Rumpler C-4	360	10.8	3.0	9.6	4.1			8.4
AEG Armored Biplane	358	9.8	3.8	11.8	2.8			8.0
Avro 530	346	15.0	3.8	16.7	3.3			6.6
Spad 11-A2	314	13.4	6.8	8.3	4.0			7.9
Hanriot Dupont 3-C2	274	12.9	4.3	16.4	3.2			6.0

Two-Seater Seaplanes

Curtis R-6	613	11.0	3.8	8.8	2.9			9.1
Curtis N-9	496	10.1	4.0	11.0	3.7			10.7
Aeromarine 39-B	494	11.3	3.8	11.7	2.6			7.5
Avro 504-L	330	13.2	4.5	13.7	3.8			7.5

Single-Seaters

Designation	Wing Area, sq. ft.	(*h*)	(*v*)	(*a*)	(*t*)			Aspect Ratio
Parnall Panther	336	11.2	3.3	13.4	2.7			4.7
Spad 20-Cl	312	11.2	3.2	11.9	3.1			5.9
Nieuport 29-Cl	288	12.3	4.3	11.1	...			6.5
Sopwith Salamander	272	9.5	4.3	18.7	2.5			6.2
Sopwith Snipe	271	9.6	4.4	16.6	2.5			6.2
Sopwith Dolphin	263	11.6	4.4	14.4	3.3			7.2
Salmson 3-Cl	257	12.5	6.6	13.0	3.2			7.3
Vickers Cl	257	9.0	4.6	13.0	3.0			5.9
Sopwith Pup	254	13.7	3.2	8.6	2.6			5.2
Spad 21-Cl	253	12.0	4.4	11.6	...			5.6
Pfalz D-3	240	10.4	3.7	8.9	2.9			5.7
S E-5	240	12.5	5.4	13.3	2.5			5.4
Sopwith Camel	240	10.2	3.3	15.0	3.0			6.2
S V A 5-C	232	10.4	5.6	11.7	3.5			5.0
Fokker D-7	219	16.5	4.0	5.2	3.3			5.6
Spad 13-Cl	215	14.2	5.2	10.0	2.9			5.2
De H-5	212	12.0	4.0	21.8	3.1			5.7
B A T Bantam	185	12.1	3.7	9.7	2.9			6.4
Nieuport 28-Cl	181	12.1	5.0	10.9	3.3			6.3
Morane Saulnier C-1	164	12.2	4.8	12.0	...			6.0

Triplanes

Caproni CA-4	2,223	8.6	3.6	10.2	4.3			13.8
Bristol-Braemer	1,905	9.5	2.8	10.0	3.6			9.6
Nieuport TT	1,100	9.5	3.7	10.9	3.7			9.1
Le Pere Triplane	870	9.1	4.3	12.7	4.2			9.6
Avro 547	498	8.8	3.3	13.8	3.9			7.8
Kirkham Triplane	309	8.8	4.5	6.3	4.5			9.1
Sopwith Triplane	231	10.2	3.0	14.7	3.9			8.0

Twin-Engined Bombing Biplanes

Handley Page V-1500	2,898	12.4	4.4	12.0	3.3			10.1
Caproni C-5	1,420	9.4	4.4	10.4	2.7			8.4
Vickers Vimy F B-27	1,320	13.0	3.6	18.1	3.8			6.4
Handley Page 0.400	1 317	10.4	3.7	10.0	4.4			10.0
Farman C-23	1,076	11.2	3.7	9.6	4.0			9.4
Martin Bomber	1,070	10.0	5.0	12.1	3.9			10.8
Farman 50-BR 2	1,026	9.1	4.1	8.7	3.3			9.7
Avro Bomber 529-A	922	9.2	3.7	13.9	3.4			8.7
De H-10	833	15.3	4.1	13.0	3.4			8.9
Boulton and Paul P-8	770	12.5	4.5	14.0	3.1			8.1
Friedrichshafen G-2	753	11.6	4.2	8.0	3.6			10.4
A E G Bomber G-4	730	9.4	4.8	5.4	3.0			9.0

Flying Boats

NC-1	2,380	21.4	6.2	11.1	3.4			10.5
F-5-L	1,397	12.6	6.3	8.5	3.2			13.0
P-5	1,296	15.5	4.5	6.6	3.2			9.5
Curtiss H-16	1,164	12.4	5.1	11.2	3.5			13.4
Curtiss H-12	1,108	12.3	7.7	10.4	3.4			13.0
Curtiss HS-2	803	12.6	5.7	13.0	3.1			11.8
Macchi M-12	656	7.8[11]	6.7	9.7	2.6			7.2
Aeromarine 40	504	12.9	6.7	11.5	2.1			7.2
Macchi 9 Bis	480	9.1	5.3	18.4	3.1			8.7
Curtiss M-F	401	15.7	8.7	11.2	3.0			10.9
Curtiss F	387	13.9	6.5	17.8[12]	2.7			8.7

[11]Omitted in average owing to large sweepback.
[12]Omitted in average owing to interplane ailerons.

at least relatively. Finally, the area of horizontal tail surface should depend on the weight of the machine or on the wing area. The ratio of length of tail to chord length varies from 2.5 for monoplanes to 4.0 for triplanes, and the corresponding average tail surface areas in percentage of wing area vary from 15 to 9. Both theory and the practice of successful designers indicate that the horizontal tail surface depends on chord length and wing area. The triplane with narrow chord has the advantage of requiring a small tail surface.

Table 9 on pages 516 and 517 gives the length of tail, or the distance from the center of gravity of the airplane to the tail hinge in terms of the mean wing chord as t and the horizontal tail surface as h as a percentage of the wing area. The product th is there shown to be nearly constant, indicating the reasonable conclusion that long tails can safely be made smaller than short tails. The flying boat class, it will be seen, has an average $th = 41.4$, which is appreciably larger than for any other class. This is no doubt due to the projection of the hull forward of the center of gravity. The twin-engined bombers also have a considerable portion of the fuselage forward of the center of gravity and are seen to require a larger value of th than the other machines.

The vertical tail surface v multiplied by the length of tail t in the same notation gives a similar coefficient tv which is larger for the flying boats, as would be expected. The large value of tv for the monoplanes is not easily explained, but due to the relatively small number of machines listed and the lack of experience with this type, I am inclined to attribute this to the designer's desire to keep on the safe side with a novel type.

The aileron area is practically a constant percentage of the wing area except that small machines which require a great degree of maneuverability have slightly larger ailerons. Apparently the span has very little effect on the required aileron area. The reason for this may be that the machines of high aspect ratio, the bombers and flying boats, are not required to maneuver rapidly. The average aspect ratios are given on Table 9 as a matter of interest. Experiments, both wind-tunnel and full-scale, indicate that although a long narrow aileron is not quite as effective in producing roll for the same angle of throw, nevertheless the moment about the hinge, which is a measure of the pilot's effort, is considerably less, and for this reason with the same percentage of wing area long narrow ailerons are more efficient than short deep ones. By using especially long narrow ailerons the percentage aileron area given in the tables might be somewhat reduced. Table 10 gives aileron data for several German machines, which are included in preparing the average of Table 9 on pages 516 and 517. It will be noted that the average aileron area for these machines is much less that the averages given in Table 9. It seems to be fairly well agreed, however, that German

TABLE 10

Name	Aileron Surface in Terms of Wing Area, per cent. (a)
Friedrichshafen	8.0
Gotha	11.4
A E G	5.4
A E G Armored	11.8
Pfalz Single-Seater	8.9
Pfalz DX II.	7.5
Albatross D-5	7.9
Fokker D-7	5.2
Fokker E-5	7.9
Rumpler C-4	9.6
Hannoveraner	9.1
L V G—CV	6.5
Rumpler G 117	8.4
Roland D-2	6.7
DFW—C-5	6.3
Average	8.0

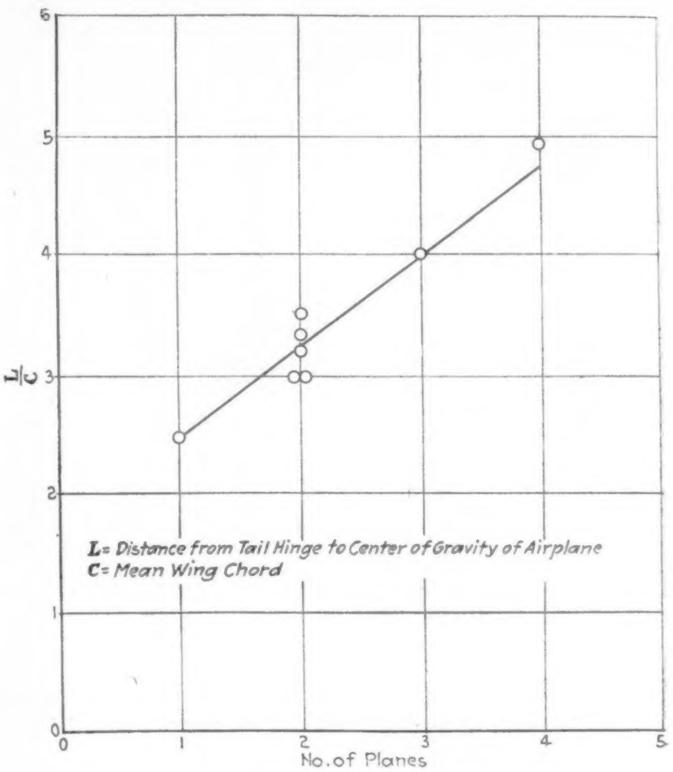


Fig. 27

planes are for the most part very sluggish on lateral control. Fig. 27 shows the relation between the length of tail in terms of the mean wing chord and the number of planes for the several classes of machines.

Determination of Control Surface Shape

To increase maneuverability without imposing an undue strain on the pilot, balanced control surfaces are being used on various machines, especially the large bombers and flying boats. The use of balanced controls was forced by necessity on large airplanes when data for their design were lacking. Naturally experience is still incomplete, but I venture to say one could now easily compile a fat handbook on how not to do it. I know of no detail of airplane design where so many good designers have gone astray. Of course, a very slight amount of balance is a timid solution which causes no trouble, but attempts at nearly complete balance require courage. Naval architects have been balancing rudders on vessels for a long time and presumably must have learned a good deal about it, but it is curious to note how little the aeronautical engineer has profited. The aeronautical people apparently have insisted on making the same old mistakes and learning at first hand.

Naval architects hinge a rudder to the rear of the deadwood with the balancing portion underhung below in the clean water flow. Forward of this underhung balancing portion the deadwood is cut away liberally. Where spade rudders are used there is no adjacent deadwood. This practice has resulted from experience which indicates poor turning qualities if the rudder is so placed as to create back-pressures on the deadwood of a nature to resist turning. Now consider the rudders on the Zeppelins, on the flying boat F-5, and similar arrangements on many other aircraft. The naval architect would never consider designing a ship with such a rig. It is interesting to note that the post-war Zeppelin, the "Bodensee," definitely abandons the old form of balanced

rudder for a more reasonable but still, to my mind, imperfect type. They have given the straight trailing rudder an overhang, but neglected to cut away the fin immediately forward of the overhanging portion. It will be interesting to observe what will be the next change.

The various types of balancing which are employed are shown in Fig. 28 and may be roughly divided into the following classes:

(1) Free simple balance as used on the rudders of the NC flying boat and Caproni biplanes and triplanes
(2) Dove-tailed balance as used on the rudders of Zeppelins and ailerons of many German airplanes
(3) Faired contour balance as used on the Hanriot C3 and Morane Saulnier C2 machines
(4) Auxiliary balance as used on many German seaplanes
(5) Overhung balance as used on the elevators and ailerons of the NC flying boats, the AEG bomber and Vickers Vimy

Regardless of the merits of the various types of balancing, the objects of balancing are first, the load on the control cable should be a minimum for all conditions of flight without overbalancing or fluttering; second, the air resistance of the added balancing portion should be a minimum; third, the added weight should be a minimum; and, fourth, from the structural point of view, the stresses introduced should be a minimum.

The free simple balanced area, if made of a double-cambered airfoil having a small center of pressure movement, can be more nearly balanced for all flight conditions than any of the other types. Owing to the circumstance that it is not preceded by a fixed surface, the area required to give proper control is, however, greater than for a trailing control surface, and the structural difficulty of providing efficient bracing is evident. The

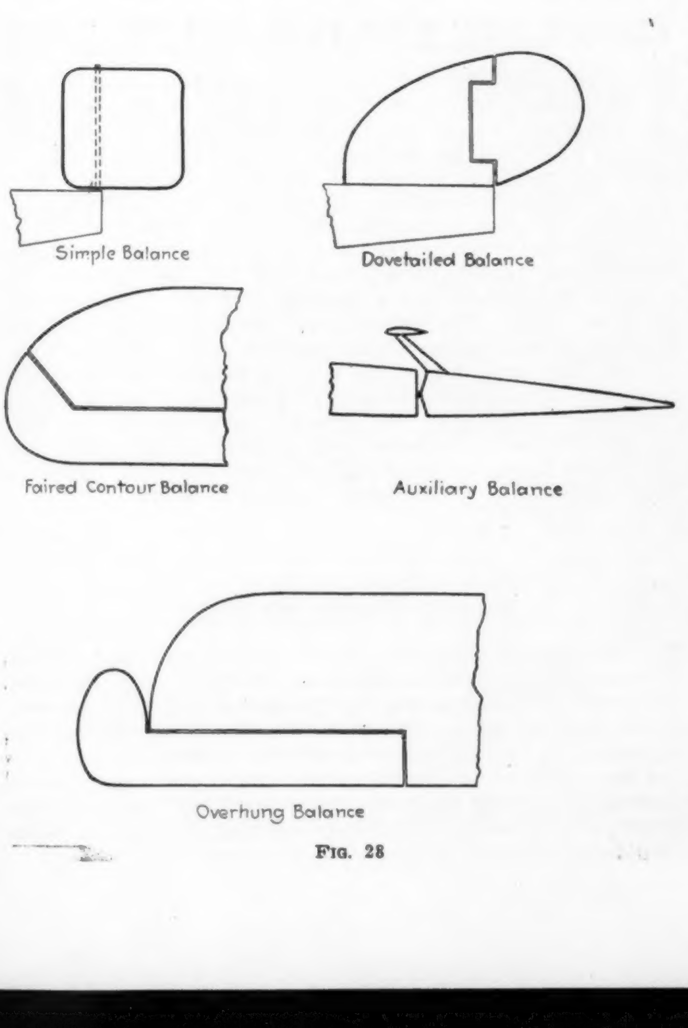


Fig. 28

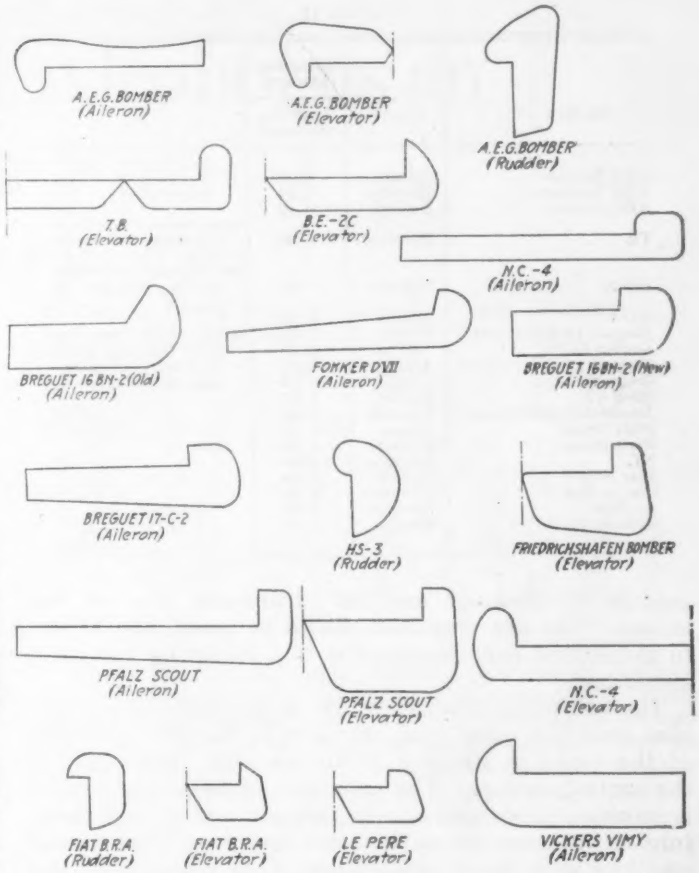


Fig. 29

free simple balance can, however, be used very advantageously for rudders on machines with a biplane tail, as in the NC boats. There the center rudder is free and is used to balance the two outside rudders. This requires "overbalancing" the center rudder and connecting all three rudders to work in parallel so as to eliminate any tendency of the center rudder to flutter. The dovetailed balance cannot be recommended as a good type. If the hinge leakage were eliminated and the movement of the controls at high speeds were very small in amount, this type of balancing would no doubt be ideal from the standpoint of low air-resistance. A movement of only a few degrees, however, will introduce a marked increase in drag, and at the same time the action of the air-flow on the balancing portion is indeterminate, due to the turbulence introduced. At large angles of the control surface, the balancing portion is blanketed by the preceding fixed surface and the effectiveness of the combination is materially reduced, due to the increased pressure on the back of the fixed surface. This form of balancing is rejected by naval architects, and it is interesting to note that in aeronautics it is becoming more rare. The faired contour balance is often used for ailerons in order to preserve a fair form of wing-tip which is supposed to confer some aerodynamic advantage. Such ailerons are quite indeterminate so far as calculation of balance is concerned, due to the uncertainty of the angle of attack of the air striking the balancing portion. At large angle of incidence of the main wings, the air spilling under the wing-tips produces abnormally high pressures on the balancing portion of the aileron and may cause overbalance and fluttering. The auxiliary balance has to date been used on only a few machines

TABLE 11

Machine	Control	Balancing Moment / Righting Moment	
AEG Bomber	Aileron	0.50	
AEG Bomber	Elevator	0.43	
AEG Bomber	Rudder	0.40	
TB	Elevator	1.00	Wind-tunnel tests show indication of instability
BE-2C	Elevator	0.64	Wind-tunnel tests show proper degree of balance
NC-4	Aileron	0.58	
Breguet 16 BN-2 (Old)	Aileron	0.83	Wind-tunnel tests by Eiffel (Résumé 1919) show degree of balancing in order shown
Fokker D-VII.	Aileron	0.45	
Breguet 16 BN-2 (New)	Aileron	0.37	
Breguet 17-C-2	Aileron	0.22	
HS-3	Rudder	0.47	
Friedrichshafen Bomber	Elevator	0.40	
Pfalz Scout	Aileron	0.65	
Pfalz Scout	Elevator	0.25	
NC	Elevator	0.63	
Fiat B-R-A	Rudder	0.55	
Fiat B-R-A	Elevator	0.36	
Le Pere	Elevator	0.26	
Vickers Vimy	Aileron	0.20	

outside of Germany and its advantages are not well known. The area required should be small, and torsion in the control surface spar due to a balancing portion is eliminated.

The overhung balance, which is perhaps more widely used than any other type, seems to be the most desirable of the types in which a balancing area forms part of the control surface. The extension or balancing portion is working in comparatively free air and should therefore at all times be unblanketed and free from mutual reactions with the fixed surfaces. It is possible to use a double-cambered surface for the extension which will operate equally well for positive or negative angles of the control surface.

Calculation of Balance

The calculation of the required amount of balancing area for control surfaces must be an approximation. If it were possible to obtain separately the lift, drag and the center of pressure coefficients for the balancing portion and the trailing portion for all conditions of flight, the required amount of balance might be calculated. But, owing to the variation in the profile used on the balancing area and on the trailing portion and to the unknown air-flow around a wing-tip, an elaborate calculation is not justified. The most desirable method for design is to employ a simple straightforward calculation which uses only the most important variables and then to compare the result with actual practice. Such compromise with a solution is common in naval architecture and yields good results if coefficients are obtained only from successful machines. For the calculation of the coefficients of Table 11, only surfaces of the overhung type are used. First the moment of the trailing portion of the surface about its hinge is calculated as the sum of the moments of fore-and-aft increments of area, on each of which the center of pressure is assumed to be a 0.3 chord length[11] from the hinge. The moment of area so obtained is a "righting moment" which it is desired to balance by the "balancing moment" of the overhanging portion of the control surface computed by graphical integration in a similar manner, except that the center of pressure is taken at 0.2 chord length[12] from leading edge. The unit pressures on the two portions of the control surface are assumed equal. The ratio of the moment about the hinges of the balancing portion, "balancing moment," to the moment of the trailing portion tending to return the rudder to neutral, "righting moment," is a coefficient of the order of 0.4 to 0.6 for control surfaces with overhung balance. The results of calculation on several machines are given on Table 11, the shapes of the various surfaces being shown in Fig. 29 on page 519.

These data would indicate that the maximum balancing moment should never be more than 65 per cent of the righting moment. On rudders and elevators where blanketing by the fuselage will tend to reduce the effective lift of the inboard portion of the control surface, this value should be somewhat less or about 50 per cent. These figures are for large machines requiring a maximum amount of balancing. For small machines correspondingly smaller values can be used. No account is here taken of the case of control surfaces which lie partially in the propeller slipstream or in an abnormal position with respect to "downwash" from the wings.

The calculation of the simple free balance type of rudder is more simple. The center of pressure is taken at 0.2 chord length from leading edges and care taken that the axis of rotation does not lie aft of this point.

The auxiliary balance type is a little more indefinite, and I am not prepared to suggest a calculation without more data or at least some knowledge of the velocity of the air flowing over the top of a wing in the region of the auxiliary surface. For large angles of incidence of the wings this velocity appears to be entirely indeterminate.

[11]Stabilizer and Elevator Pressure Distribution. Bulletin of the Experimental Department, Airplane Engineering Division, U. S. A., vol. II, No. 3, December, 1918.

[12]"Airplane Control Surfaces," J. C. Hunsaker and T. H. Huff, *Aviation*, vol. I, No. 5, Oct. 1, 1916.

GASOLINE EVAPORATION LOSS

It is estimated that in the Mid-Continent field alone, during 1919, over 122,000,000 gal. of gasoline evaporated while the crude was stored for the average period of five days. This is borne out by the gravity tests, which show that in some instances the gravity of the crude decreases 5 deg. Baume between the well and the refinery. The total evaporation loss averages 6.2 per cent by volume. From two-thirds to four-fifths of this can be saved at low cost. One company has tight-top tanks with a pressure of 1 lb. per sq. in. on its crude-oil flow tanks, and a vacuum of 2 in. of mercury on its stock tanks. The vapors from these tanks are treated at a compression plant whose gasoline output runs as high as 2000 gal. per day more on a warm than on an extremely cold day. On adjoining properties where there are no tight-top tanks the bulk of this gasoline is wasted in the air. An installation to conserve and recover the gasoline from the vapors from the crude oil will pay for itself within a short period.—A. W. Ambrose, Bureau of Mines.

FARM CROP PRICES

In the past 10 years our population has increased 15 per cent, while there was a decrease of 3.6 per cent in the total production of bread grains for the period 1916-1920 as compared with the period 1911-1915. Furthermore, our increase in population has been confined entirely to the cities, for there are less people on the farms to-day than 10 years ago. In the face of these facts the present low level of prices for farm crops cannot continue indefinitely.—Finley P. Mount in *Farm Implement News*.

Researches on Alcohol as an Engine Fuel[1]

By Harold B. Dixon[2]

THE object of these researches was to obtain data for comparing alcohol with gasoline and other hydrocarbons as a fuel for motor-vehicle and other small engines, and to determine how far the properties of alcohol are modified by admixture with other volatile liquids. The work was undertaken at the request of the Departmental Committee appointed in 1918, by Walter Long, first Lord of the Admiralty, to inquire and report on the utilization of power alcohol. As a member of the Committee, I undertook to make experiments on the burning of alcohol and other vapors on the same lines that had been followed with permanent gases, especially on the ignition of the mixtures and on the movements of the flame in explosions. The work is by no means finished and I propose to continue and present a more complete report later on.

Vapor Pressures of Alcohol and of Alcohol Mixtures

On comparing alcohol with other liquid fuels, we find certain properties which affect its use, such as its small vapor pressure at low temperatures, its high latent heat of vaporization and its attraction for and its miscibility with water. For instance, air bubbling through liquid alcohol does not form an explosive mixture, for the amount of vapor carried by the air is too small; but air bubbled through pentane, hexane, benzine or ether in each case forms a combustible mixture with too much vapor in it to explode. The alcohol must be heated to give off enough vapor to form an explosive mixture with air; the other mixtures must be diluted with more air to bring them within the explosion limits. Hence the difficulty with an ordinary gasoline engine of starting off cold with alcohol. There are several ways of surmounting or avoiding the difficulty. If the engine is designed to burn alcohol, using a long stroke and a high compression, the cylinder may be flooded, either directly or through the throttle-valve, with a little liquid alcohol in the form of spray, which is warmed by compressing air in the cylinder. Crossley Bros. are running one of their 5-hp. single-cylinder engines of 4¼-in. bore with a 6-in. stroke arranged to give a compression ratio of rather over 8 to 1. With either method of flooding there is no difficulty in starting from cold with ordinary "industrial" alcohol. Running at full load and 500 r.p.m., the engine was remarkably silent. The spray from the exhaust, thrown out while the condenser was cool, was found to be slightly acid, though no evil effects of acid could be found on the exhaust or throttle-valve, or of the cast-iron piston, after a fortnight's running.

Those who wish to avoid the starting difficulty will look to some mixture of alcohol with other liquid which will readily form an explosive gas with air in the cold. As a guide in making such mixtures, the vapor-pressures of pure alcohol, pure benzine, pure hexane, a 20-per cent mixture of hexane with 80 per cent alcohol, pure ether, natalite, a mixture of 45 per cent ether with 55 per cent alcohol, a 20-per cent ether and 80-per cent alcohol mixture, and a 20-per cent benzine mixture with 80-per cent alcohol have been determined, and the results are given in the accompanying table.

VAPOR PRESSURES OF LIQUID FUELS IN MILLIMETERS OF MERCURY

Temperature, deg. cent.	0	10	20	30	40	50
Temperature, deg. fahr.	32	50	68	86	104	122
Ether	180	280	433	637	..	..
Natalite (45 per cent ether and 55 per cent alcohol)	165	250	380	547	..	..
20 per cent ether and 80 per cent alcohol	73	105	162	247	350	500
Alcohol	14	22	42	79	135	217
20 per cent hexane and 80 per cent alcohol	30	46	80	141	219	328
Hexane	44	76	121	184	276	400
20 per cent benzine and 80 per cent alcohol	37	56	90	142	215	325
Benzine	28	45	75	120	180	263

It is remarkable that, while the vapor-pressures of pentane, hexane and ether are lowered by admixture with alcohol, as is usual with miscible liquids, the vapor-pressure of the benzine mixture is above that of either of its constituents. When air is bubbled in the cold through a 20-per cent benzine-80-per cent alcohol mixture the resulting stream of vapor and air is highly explosive. This mixture has been tested in motor-vehicle and aeronautic engines, and no difficulty has been found in starting up in the cold. With the single-cylinder kerosene engine of Crossley Bros. the volume of liquid fuel consumed per brake horsepower was about 3 per cent less with the 20-per cent benzine mixture than with industrial alcohol alone.

The difference shown by the benzine-alcohol mixture is no doubt due to the small attraction between the two liquids. The addition of water to the mixture diminishes the attraction, and a dilution is soon reached when the liquid separates into two layers, the denser watery liquid below containing less benzine, and the lighter liquid above containing more benzine, than the original mixture. Also as the temperature falls the solubility of benzine in alcohol diminishes.

At the room temperature 15 deg. cent. (59 deg. fahr.) the 50-per cent mixture separated into two layers when 10 cc. of water were added to it, the lighter liquid, rich in benzine, having a volume of about 20 cc. In other words, benzine added to alcohol containing 20 per cent of water is only partially soluble at 15 deg. cent. (59 deg. fahr.). When 12 cc. of water had been added the volume of the lighter liquid separating out was about 60 cc. The higher the percentage of alcohol the more water is required to separate the mixture into two liquid layers.

Similar experiments made with alcohol-hexane mixtures showed that the addition of water caused a separation at lower temperatures than with the corresponding alcohol-benzine mixtures. For instance, with equal volumes of alcohol and hexane, it requires the addition of only 7 per cent or 3.5 cc. of water to the 50 cc. of alcohol to separate the liquids at 17.4 deg. cent. (63 deg. fahr.), whereas the same water added to equal volumes of alcohol and benzine required the whole to be cooled below the freezing point—1.45 deg. cent. (29.4 deg. fahr.) before producing separation. For these reasons I have mainly worked with alcohol mixtures containing between 20 per cent and 30 per cent by volume of benzine.

Owing to the heat of evaporation of liquid alcohol being greater than that of gasoline or benzol, it is important to warm the intake when using alcohol mixtures. This can be conveniently done by the device used in the Crossley kerosene engine of by-passing all or a part of the exhaust gases around the intake.

[1] Abstract of paper submitted to the Fuels Section of the Imperial Motor Transport Conference, at the Royal Automobile Club, London, Oct. 18, 1920.

[2] University of Manchester, Manchester, England.

Ignition Temperatures of Alcohol and Other Vapors

Two methods were used for the determination of the ignition temperature of alcohol vapor, and in each case comparison experiments were made with other vapors. Both methods had previously been used for determining the ignition temperatures of permanent gases, and the chief alterations required to be made in the apparatus were (*a*) means of keeping the stored mixtures, the connecting tubes and the ignition vessel itself above the condensation point of the vapors, and (*b*) the substitution of glass, silica or metal joints for all rubber connections which would have been acted on by the vapors. In the first method, the vapor and the air or oxygen were heated separately by passing them upward through two concentric tubes fitted into a long electric furnace, the temperature of which could be slowly raised and accurately measured. The vapor passing up the narrow inner tube issued at a jet with a sufficient stream to carry the combustible gas rapidly away from the solid silica surrounding the orifice, but not so quickly as to cause the ensuing mixture of combustible vapor and oxygen or air to come into contact with the heated wall of the large outer tube before the flame appeared.

The catalytic effect of a heated solid on the ignition of the permanent gases had been already noticed. All combustible gases and vapors when heated with oxygen undergo a "preflame combustion," which at the ignition point becomes rapid enough to heat up the gases automatically until the flame appears. Solids affect this pre-flame combustion in two ways; they increase the rate of combination, thereby generally lowering the ignition temperature, but when the flow of combustible gas is very slow the solid may start the preflame combustion, but, by conducting away the heat, may prevent the automatic heating up, so that no flame appears, though the orifice of the tube is visibly red-hot. It was necessary to determine by experiment when the rate of flow through the jet and when variations in the diameter of the outer tube ceased to affect the ignition temperatures.

In the case of the vapors now experimented with, the preflame combustion is much more marked than with such gases as hydrogen and cyanogen. All the vapors underwent preflame combustion as they mixed with the oxygen and passed along the wall of the outer tube, so that the gases would often burst into flame near the upper end of the furnace, and fire back some seconds after the vapor had issued from the jet. This contact action with the wall was particularly noticeable with ether. To overcome this difficulty, two methods were tried; (*a*) by increasing the airstream to render the mixture non-inflammable by dilution before it reached the wall, and (*b*) by making the flow of vapor from the jet intermittent and timing the inflammation. A combination of these methods was finally adopted; a wider outer tube was used, to increase the relative quantity of air, and the flow of vapor could be started at any moment. When the vapor ignited within a half-second of its issue from the orifice, the temperature of the tube was taken as the ignition temperature.

IGNITION TEMPERATURES OF VAPORS HEATED SEPARATELY

	With Oxygen	With Air
Alcohol ...	510-515 deg. cent.	595-600 deg. cent.
	(950-960 deg. fahr.)	(1102-1112 deg. fahr.)
Pentane ...	550 deg. cent.	560-570 deg. cent.
	(1022 deg. fahr.)	(1040-1058 deg. fahr.)
Ether	235-240 deg. cent.	560-580 deg. cent.
	(455-464 deg. fahr.)	(1040-1076 deg. fahr.)

The ignition temperatures of alcohol vapor coming into contact with oxygen or air heated to the same temperature were fairly definite; those of pentane vapor moderately so. It is noticeable that pentane ignited at nearly the same temperature, whether the vapor came into contact with pure oxygen or air, whereas alcohol ignited more readily in oxygen. Ether presented a very abnormal property; when all contact with solids was avoided, ether fired below 240 deg. cent. (464 deg. fahr.) in oxygen, but had to be heated to nearly 580 deg. cent (1076 deg. fahr.) before it would inflame immediately in air. When ether vapor and air are allowed to flow along a tube and are in contact with the heated walls, the mixture gradually heats up, and the ignition-temperature, as measured by the temperature of the tube, is quite indefinite.

The second method of determining the ignition temperatures of alcohol and other vapors was to compress mixtures of the vapor with air or oxygen in a steel cylinder by a falling weight driving in an air-tight piston. This method had been carried out successfully with many of the permanent gases, and could be used for the vapors of volatile liquids, provided the reservoir containing the mixtures, the connecting tubes and the cylinder itself were maintained at a sufficiently high temperature. In most of the experiments the cylinder was kept at 50 deg. cent. (122 deg. fahr.) by a water-jacket, in which the hot water was well stirred. In some experiments a temperature of 60-70 deg. cent. (140-158 deg. fahr.) was used, and in a few the cylinder was at 100 deg. cent. (212 deg. fahr.).

The rise of temperature produced in the mass of the gas by the sudden compression is nearly independent of the wall-surface, which, of course, cools by contact with the layer of gas next to it, and, so far as it acts, lowers the pressure. There is no evidence that the steel surface promotes combustion by contact action; indeed, since the temperatures of ignition calculated by the adiabatic law were practically constant, whether the cylinder was at 50 deg. cent. (122 deg. fahr.) or over 80 deg. cent. (176 deg. fahr.) at the moment of compression, such action, if any, must be negligible.

A greater difficulty arises in calculating the ignition temperatures from the observed compressions necessary to fire the mixtures, since the recorded measurements of the specific heats of these vapors vary considerably. However, the latest determinations made by Thibaut give values for the ratios of the specific heats which appear probable from two considerations; (*a*) the method by which they were obtained, and (*b*) the agreement in the most doubtful case, that of ether vapor, between Thibaut's ratio, 1.052, from 0-300 deg. cent. (32-572 deg. fahr.) and the ratio found by us from a direct determination of the velocity of sound in ether vapor at 50 deg. cent. (122 deg. fahr.), viz., 1.058. We have accordingly taken the round figure 1.05 for the mean ratio of the specific heats for ether between 50 deg. cent. (122 deg. fahr.) and 350 deg. cent. (662 deg. fahr.). From the velocity of sound in pentane vapor at 50 deg. cent. (122 deg. fahr.) we have taken the mean ratio between 50-500 deg. cent. (122-922 deg. fahr.) at 1.065.

The temperatures of ignition calculated from the compressions must be regarded only as approximations. What is more important, especially for the engine designer, is the fact that this method gives with a near approach to accuracy the actual volume change necessary to fire the particular mixture by adiabatic compression, starting from any known temperature.

The ignition compressions were measured by a system of trial and approximation. For each mixture the compressions were gradually increased until the mixture exploded; in another series the compressions were gradually reduced until the mixture did not explode. Then experiments were made in the neighborhood of these two points, and a mean compression taken between the nearest exploding and non-exploding trial. In some cases the compressions "overlapped," a non-explosive mixture being fired by a slightly less compression in a second trial. In such cases I have inclined to the lower value as the safer figure to give.

The ignition temperatures by adiabatic compression for alcohol with oxygen and with air are what we should expect from the results at atmospheric pressure. At the high pressure the ignition temperatures are lower. With pentane the results show a similar agreement, but with ether the results are discordant. The ignition temperatures in the heated tube at atmospheric pressure were much lower with oxygen, and much higher with air than the temperatures found by compression.

Movements of Flame Through Explosive Mixtures

The mode in which the flame spreads throughout an explosive mixture of gases, and the rapidity of chemical combustion taking place in the flame, depend not only on the nature of the gas mixture, but on the method of firing. When an explosive mixture is lit by a flame or a hot wire near the open end of a tube the flame travels through the mixture slowly at first, then more quickly and jerkily. Fired near the closed end of a tube, the same gas will propagate a flame with greatly increased velocity. When the gas mixture is fired by a spark the travel of the flame depends both on the intensity and on the position of the spark. When the spark is passed close to a surface the flame starts slowly; when the spark is at a short distance from one end the sound wave starting backward from the spark, and traveling faster than the flame, reaches the near end, and is reflected back passing through the flame and hurrying it up. Similarly if the tube is short, the sound wave starting forward from the spark may reach the far end of the tube before the flame and being reflected back passes through the advancing flame, checking its advance, but causing more rapid combination where the sound wave passes. These reflected waves, due to sound, are more intense than the original flame, and they become more intense by the combustion they promote. It may thus happen that the explosion only becomes brilliant after the flame has completely traversed the mass of combustible gas. In this brilliant flame which can be analyzed photographically on a rapidly moving film, the sound waves can be seen crossing and recrossing the tube from end to end. The flame traversed by these intense waves may be and usually is so much more luminous than the original flame that the latter may escape detection altogether. My photographs have proved that the explosion wave is not set up at once, but that the flame starts slowly, and gradually increases in velocity and intensity, especially when sound waves are reflected through it. At a certain point in its course the explosion wave may be started; this point is marked by several distinct characteristics. The speed of the flame increases, but it is no longer varying, but constant, and it continues at a constant velocity so far as the gas mixture extends. As it travels faster than sound in the unburnt gas, it can send no pressure wave in front of it. At the moment when the explosion wave is started forward a well-marked wave is sent backward through the burning gases, which I have called the retonation wave, and a dark region is left between the two bright waves. When the explosion wave strikes the end of the tube it sends back a reflection wave, which is easily photographed as it passes backward through the heated gas, in many cases undergoing secondary combustion, e.g., the burning of carbon monoxide formed in the explosion wave.

If now the tube is of such a length that the explosion wave has not been set up by the time the flame reaches the end of the tube, a reflected wave comes back across the flame, and though this promotes combustion, and may become very intense at the first or second reflection, it does not set up a true detonation, and the flame lasts much longer than if the explosion wave had been started. But the flame may reach the end of the tube at the precise moment when the explosion wave started. In this case the wave of retonation comes back with the reflection wave superposed on it, with the result that it is scarcely distinguishable from the explosion wave itself. This is the extreme instance where a reflected wave differs wholly in velocity and intensity from the impinging wave. The chemical reactions appear to be as rapidly completed in this wave as in the true explosion wave. It is evident that in the original flame the combustion is slow, and Bunsen's dictum that the spread of the flame "is synchronous with complete combustion" is quite erroneous. The size and shape of the explosion vessel are important elements in determining the nature of the flame, and so is the position of the spark.

A careful comparison of the photographs yields an unexpected result: the alcohol flame *starts faster* than the hexane, pentane and ether flames, which keep close together, while the benzine flame is left far behind. But though the alcohol flame is quick off the mark, it cannot increase its pace like the others do. Hexane catches it in less than 0.007 sec. and ether and pentane a moment later.

There is a general opinion that if the charge is fired in any part of the combustion-chamber of an engine by "spontaneous ignition," i. e., by compression before any flame reaches it, this portion of the charge necessarily detonates. Nernst has given his authority to this view. Now, it is possible to photograph on a rapidly moving film and so analyze the flames produced by the rapid compression of gas mixtures. It has been found in all cases of firing by adiabatic compression that the flame starts comparatively gently, and does not set up detonation immediately. Indeed, many gas mixtures, fired by compression, do not set up the explosion wave, but continue to burn quietly while they push out the piston. Such flames, in spite of the rapid compression, are singularly free from the "sound waves" that are so strongly marked when the gases are fired by a spark. Of course, an explosion wave is more readily set up in a hot compressed gas than in a similar uncompressed gas, but compression does not necessarily set up the explosion wave. In this connection I should like to give a word of warning against any conical pocket or recess in the combustion chamber; e. g. in the spark-plug; for it is much easier to produce firing by compression when the gas is driven toward the small end of the cone.

Detonation of Alcohol and Other Vapors

The detonation of a gas mixture, as of a high explosive, is due to the passage of an immensely rapid shock of wave through the substance, the intensity of the shock being continually renewed by the chemical reactions it produces as the shock passes from molecule to molecule. The explosion wave, *l'onde explosive*, discovered by Berthelot, and observed almost at the same time independently by Le Chatelier and myself, was explained by Berthelot as due to molecular impacts causing a disc of flame to move forward with the mean velocity of the molecules themselves while they still retain all the heat due to the chemical change. The explosion wave is therefore a definite physico-chemical constant only depending on the nature of the burning substance, and calculable when the chemical change and the heat evolved are known. Although certain factors in Berthelot's formula have been shown to be erroneous, his fundamental idea connecting the rate of the flame with the velocity of the reacting molecules has been retained. It is now seen that in the explosion the mass of reacting gas moves bodily forward, comes to rest and swings back again. According to Professor Jouget, the explosion wave travels forward with the velocity of sound in the forward moving gas, which is itself moving with nearly the same velocity, and therefore the actual rate of the explosion wave is equal to the sum of these two velocities, or twice that of sound in the burning gas. Fortunately this conclusion is easy to verify with the camera. A sound wave can be despatched through the burning gases behind the explosion wave, and its movement can be photographed if it is not too close to the intensely bright explosion wave. Such a sound wave travels nearly as fast as the explosion wave it is following, the difference in rate being clearly due to the gas, in which it is propagated, having already lost a little of its forward velocity.

The close approximation between the measured velocities of the explosion wave and those calculated from Professor Jouget's formula show, I think, that the chemical combination must be very rapid in the wave, whereas in the region of ordinary explosion the flame traverses the vessel, leaving a large percentage of slowly burning gas behind it. In the explosion wave the collisions of molecules are so violent that most of them cause chemical change where this is possible, and the flame is usually short-lived and intense. In ordinary explosions only a small proportion of the molecular collisions are chemically fruitful, and the flame continues to burn long and quietly.

Now, the explosion wave or detonation has the effect of a hammer-blow on the walls of the vessel; hence the use of

high explosives in which the explosion wave is set up by a detonator. Detonation must be avoided in the internal-combustion engine; hence it is necessary to determine the conditions under which it can be set up in alcohol and other vapors.

All the vapors tried will detonate when they are mixed with oxygen and fired in a long tube. When mixed with air under atmospheric pressure alcohol and ether just propagate the explosion wave, while pentane and benzine are just beyond the limit. But though these vapors will not detonate with air under atmospheric pressure, it is evident that an increase in pressure such as is used in a motor-vehicle engine would bring them within the range of detonation.

As might have been predicted from previous work on cyanogen, ethylene and acetylene, it was found that alcohol, ether, pentane and benzine all gave faster rates of detonation when mixed with an amount of oxygen that was insufficient for complete combustion. This is explained in part by the formation of carbon monoxide, either directly or indirectly, in the wave-front, while the formation of carbon dioxide is only possible where the flame is cooler, behind the wave-front; and possibly by the separation of free hydrogen. In the explosion of benzine with insufficient oxygen large quantities of finely divided carbon were deposited, some of the molecules probably breaking up by impact in the wave-front into free carbon and hydrogen. The accuracy with which the rate of the explosion wave can be measured has suggested its use in determining the temperatures reached in explosions and the specific heats of the gases concerned.

Conclusion

In the course of these researches it has been made clear that alcohol possesses most of the properties required in an engine fuel. As compared with gasoline, its lower calorific value is almost compensated by the greater compression at which it can be used and this property, of high ignition temperature under compression, is hardly altered by admixture with 20 per cent of benzine or of gasoline itself. Such a mixture readily starts in the cold, and has been shown to run very smoothly, and without knocking in an engine.

I have not touched on the question of denaturing, but I would urge that the less methyl alcohol employed the better for the liquid as a fuel. By cutting down the wood spirit the strength of the explosion is increased, and it should not be necessary to maintain the present high proportion since the nauseous taste of crude wood spirit is largely due, not to the methyl alcohol itself, but to a small quantity of a less volatile constituent. I think there would be some advantage if one or two standard alcohol mixtures were authorized, one of which could be used in existing engines, with slight adjustments.

TIRE PRODUCTION IN THE UNITED STATES

ASSUMING five tires per car as the average annual consumption in 1913 and four and one-half tires per car the present consumption, owing to the wider use and longer life of cord tires, the American demand for tires has grown from about 6,275,000 in 1913 to over 34,000,000 in 1919, or nearly five and one-half times that of 1913. The 1919 production showed an increase over 1917 of 23 per cent in casings and 48 per cent in tubes. At an average of $30 per tire the value of the 1919 product of casings under 6 in. was about $1,050,000,000, to which may be added $172,500,000 for the tube production at an average of $5 per tube, making a total of $1,222,500,000 for the pneumatic-tire output of 1919, exclusive of giant cord tires for heavy trucks.

In 1919 approximately 60 per cent of the india rubber consumed in the United States was used for tires and tire sundries, as against 75 per cent in 1917 and 58 per cent of the imports for the fiscal year 1913, indicating the greater supply of the raw material. The actual quantity of crude rubber used in 1919, however, was almost five times that for the year 1913, as against about three and one-half times that for the year 1917.

Truck-tire production for original equipment showed a continuous growth during the war period. In 1918 it had increased to over nine and one-half times the 1913 production for this purpose and in 1919 to nearly 13½ times the 1913 production. Pneumatic-tire production for the original equipment of passenger cars reached its highest figure for the year 1917, when it was more than three and three-fourths times the 1913 output. This volume of business was not quite reached in 1919, but the output for original equipment that year was more than three and one-half times the 1913 production for this purpose. It is seen, therefore, that while 1,940,000 tires sufficed for new equipment in 1913, no less than 7,475,888 were required in 1917, and 7,896,064 in 1919, an increase to over four times the 1913 requirements. Although the greater volume of increase has been in pneumatic tires under 6 in., the greater rate of increase has been in solid and large pneumatic tires for trucks.

Of the 7,565,446 motor vehicles registered in the United States during the calendar year 1919, some 750,000 were trucks, so that about eight and one-fourth times as many pneumatic tires under 6 in. as truck tires were in use last year, the number of each sort, exclusive of spares and replacements, being approximately 27,235,392 pneumatics under 6 in. and 3,000,000 truck tires. One additional tire per car would be conservative estimate for spares and replacements, making the totals 34,044,240 pneumatics and 3,750,000 truck tires. With nearly 38,000,000 motor-vehicle tires in use it is not surprising that some 25,000 vulcanizers are kept busy.

On the basis of 20 lb. of rubber as an average per car for regular equipment, and one-fourth of that extra for one spare per car, 170,221,200 lb. of rubber was being used last year in American tire casings under 6 in. alone, an amount almost equal to the total india rubber imports of the United States for the fiscal year ended June 30, 1915, and equal to nearly 32 per cent of the United States india rubber imports for the calendar year 1919.

Despite the fluctuations of 1914 to 1917, inclusive, American automobile tire exports have shown a great and steady growth, the value of the foreign business in 1919 having increased to almost seven times what it was in 1913.—*India Rubber World.*

BOARD OF SURVEYS AND MAPS

AS was announced in the July 1920 issue of THE JOURNAL, Conrad H. Young, a member of the Society, residing at Washington, is serving as its representative on the advisory council of the Board of Surveys and Maps which has been organized for the purpose of coordinating and making suggestions in connection with the map-making effort of various departments of the Government. The main purpose is to bring about the preparation of a national topographical map which will incorporate to the greatest extent possible information of value to the nation's industries. So far as the automotive industry is concerned, the work is being followed with particular reference to highway and air transportation. It has been suggested that the mapping information include the indication of what roads in the country are developed and what types of road have been constructed in the developed portions. It can readily be understood that such information is important in connection with motor truck transportation.

The members are requested to send to the office of the Society at New York City any suggestions which they may care to make in connection with this very important and advanced map work.

Piston-Rings

By L. G. NILSON[1]

METROPOLITAN SECTION PAPER *Illustrated with* DRAWINGS

THE free, resilient, self-expanding, one-piece piston-ring is a product of strictly modern times. It belongs to the internal-combustion engine principally, although it is applicable equally to steam engines, air-compressors and pumps. Its present high state of perfection has been made possible only by the first-class material now available and the use of machine tools of precision. As automotive engineers we are concerned only with the modern piston-ring, but it is interesting to trace its gradual evolution from the former piston-packing. The word piston-ring does not appear in old books. In early machinery, pistons were constructed so that they could be packed; hence the wording "piston-packing" or "packing-rings" was used.

EARLY USES OF PISTONS

The idea of conveying water through a cylinder by moving pistons is very old. The Archimedean screw, invented about 260 B. C., can be considered a continuous moving piston. That and the early chain pumps which were developed later had no provision for packing but, as they were used only for low pressures, the power loss due to leakage probably amounted to less than the extra power that would have been required if they had used packing in poorly-finished cylinders. Early writers claim that the native metallurgists of Asia and Africa had blowing machines which made use of pistons moving in cylinders. This was before the time of Ctesibius of Alexandria, accredited as the inventor of the air-pump, about 150 B. C. These air-pumps were provided with packing. The air-pump was reinvented by Otto von Guerick of Magdeburg about 1650 A. D. His pumps were used for producing vacuum as well as compression, so they must have been provided with effective packing.

The Marquis of Worcester invented a pump, or "water commander," about 1633. Papin invented an atmospheric engine about 1695, and Newcomen another, about 1705. The Newcomen engine cylinder was open at the top; the piston was suspended by a chain from one end of a walking-beam above, the pump-rod at the other. The opposing pump-rod weight kept the chain tight and helped raise the piston when steam was admitted at the cylinder bottom. When cold water was sprayed into the cylinder, the steam condensed and created a vacuum. Atmospheric pressure forced the piston down. This required a tight-fitting piston. Newcomen therefore covered the piston periphery with leather. The piston top was covered with water, dripping from a tank above, to keep the leather packing tight, and also to prevent the piston from becoming too hot. James Watt invented his single-acting engine in 1764, and the double-acting engine in 1782. Because the condenser was separated from the working cylinder, higher temperatures were encountered and consequently he had to devise better methods of packing. He obtained a patent in 1769 on a piston packed with "lubricator," preferably mutton tallow, instead of water, although hemp and tallow had been used in the stuffing-box invented by Sir Samuel Moreland. In a pamphlet published by Boulton & Watt in 1785, instructions were given in great detail for handling and packing their engine. They showed how to plait a gasket from untarred rope yarn, flatten it out with a hammer and beat it down into position in the piston with a mallet. Melted tallow, a layer of oakum, another rope and more oakum were then to be packed in for a depth of 3 or 4 in. This was to be backed up by segments of lead and pieces of wood radiating from the center of the piston. The whole assembly was then to be bolted together between flanges to give the necessary pressure against the cylinder wall. They advised that the packing be beaten down solid, but not hard enough to create unnecessary friction and prevent easy running, and that an abundance of tallow be used at first, the quantity needed later being less after the cylinder "grew" smooth. It is hard to realize the patience, energy and resourcefulness these early engineers must have had and the difficulties they had to overcome in building engines with the material and tools then available. A 50-hp. Watt engine is described as having had a cylinder of 6-ft. diameter and 8-ft. stroke.

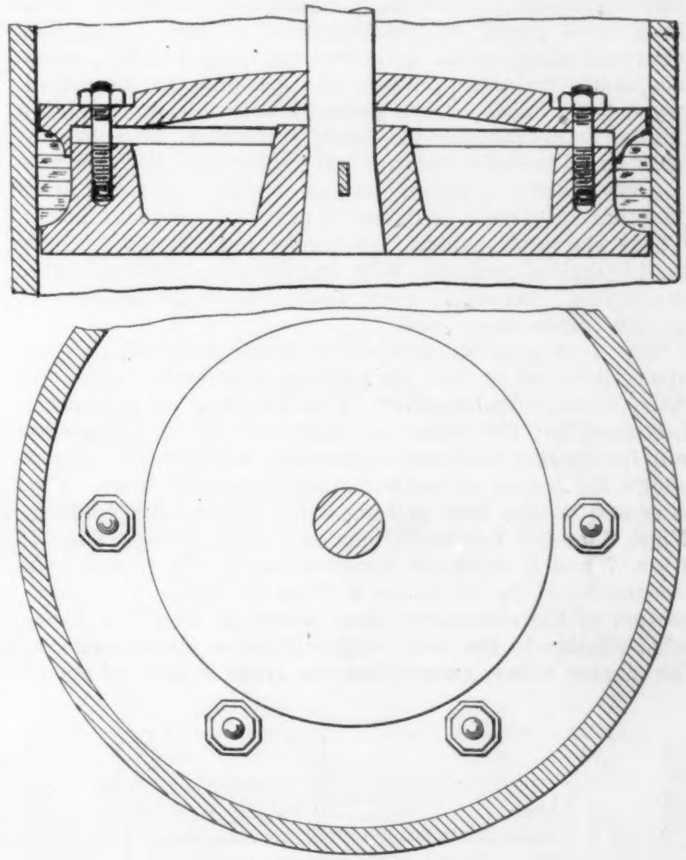


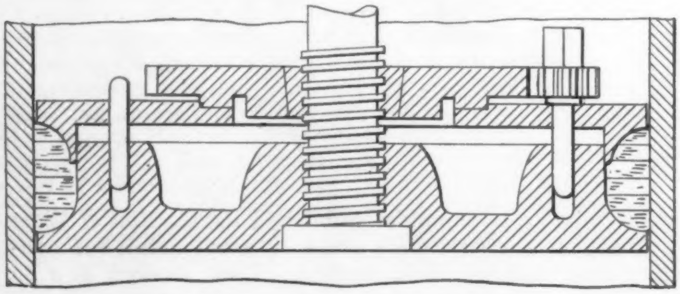
FIG. 1

Early pistons were usually provided with flanges or segments bolted near the periphery to provide space for the packing. When the flanges were screwed together,

[1]M. S. A. E.—President and chief engineer, Nilson-Miller Co., Hoboken, N. J.

the packing was squeezed out toward the cylinder walls. In 1813 Murdock & Aiken of Glasgow invented piston packing, using brass rings as a substitute for hemp. Another piston known as Jessop's had a closely wound helical spring placed between the flanges and backed up with hemp and tallow. The British patent records show a great variety of piston packings, using almost every conceivable combination of metallic fibers and lubricating materials such as wool, hemp, jute, flax, cotton, felt, burnt hair, leather, grass, sawdust, cork, paper, asbestos, lead, wire gauze, quicksilver, rubber, tallow, graphite, charcoal, lamp black, carbonate of soda, sulphur, alum, soapstone, molasses, paraffin and stearin. As the art advanced and higher steam pressure with its accompanying higher temperatures was used, it became more evident that an all-metallic packing was necessary. We find now a great variety of pistons having segments of metal fitted together in various fashions to provide leak-proof joints. These segments usually are forced against the cylinder wall by helical springs. With smaller cylinders and better machining, concentric rings backed up with flat springs on the inside were used.

Fig. 1 on page 525 is a steam piston with the packing space designed so that the packing is expanded when the flanges are drawn together. Fig. 2 is identical as to packing space, but the flange is drawn down by a single geared nut for quicker and more convenient adjustment. Fig. 3 shows the Jessop piston with helical packing-rings. Fig. 4 is one of the first pistons using all-metallic packing. Figs. 5 and 6 are variations in the details of Fig. 4. Figs. 7 and 8 show the construction of the piston in a locomotive of the Stanhope & Tyne Railway. The cross-section of the concentric rings shown in Fig. 7 is somewhat similar to the construction of some piston-rings on the market today, except that the rings in the old steam piston were not self-expanding but depended upon flat springs placed on the inside, as shown in Fig. 8, to make the piston steam-tight. Fig. 9 shows multiple self-expanding rings. Figs. 1 to 9 are taken from illustrations of Steam Machinery and Steam Naval Architecture, by John Weale, London, 1843. A number of the drawings are dated 1838.



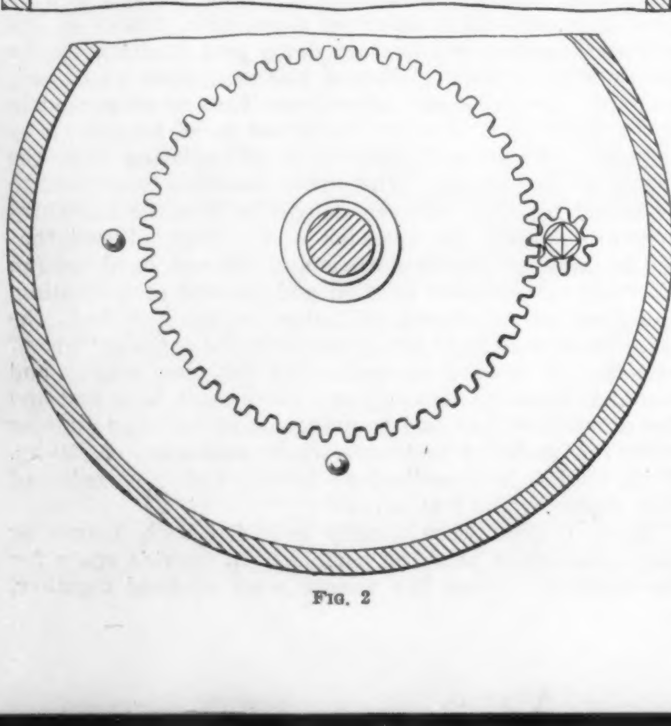


Fig. 2

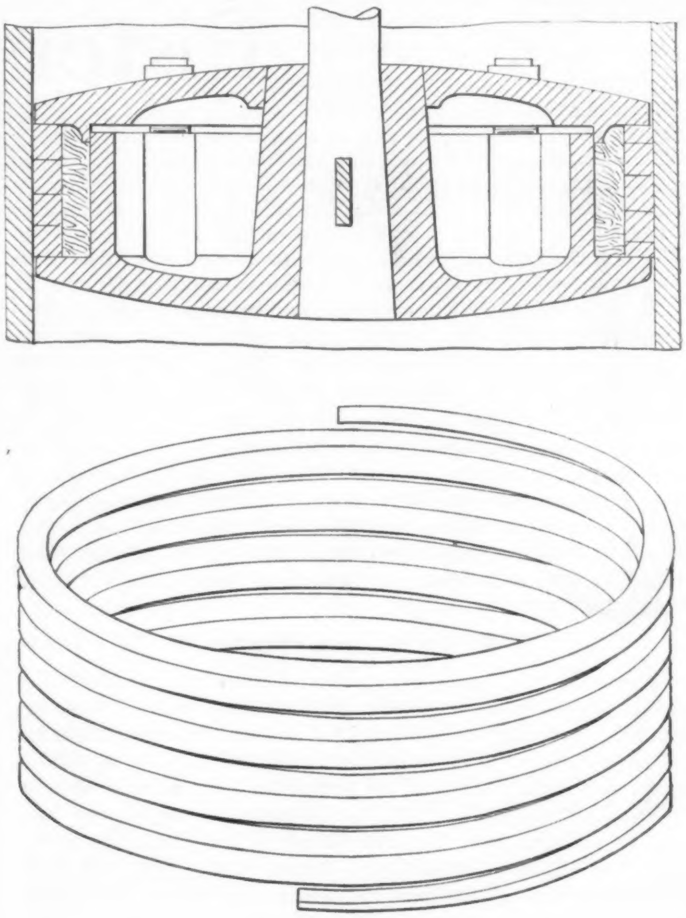


Fig. 3

When the internal-combustion engine appeared, because of its higher temperature it was not only natural to adopt the simplest form of self-expanding packing rings but, with single-acting trunk pistons, the self-expanding ring became a necessity. Actual experience soon showed that the simplest possible form of ring was the best because, under the influence of heat, the lubricating oil would turn to carbon and cement the rings into a solid mass in the grooves of the piston. Under such conditions a single-piece ring would be preferable to the combination shown in Fig. 9, for instance.

Piston-Ring Design

The actual detailed construction and functioning of piston-rings for automotive purposes will now be considered. In doing so, we can treat the different types or classes of ring and discuss their merits from that standpoint only, avoiding reference to rings of any particular manufacture unless it becomes necessary.

The basic requirement of a piston-ring is to prevent the gases in a combustion-chamber from passing a piston moving in a true cylinder. If this were the only requirement the task would be easy, but it must be accomplished with a minimum amount of friction. This requires a light and uniform radial pressure against the

cylinder walls. The best material and a degree of accuracy bordering on perfection are necessary in the manufacture, as well as correct final fitting which varies slightly according to the peculiarities of different engines.

For the last 25 years I have talked often with practical men about piston-rings to obtain their opinions regarding different details. I have written letters recently to nearly all the manufacturers of piston-rings in the United States and to a number of engineers, asking for suggestions and data on this subject. Some replies are very good, but it is surprising how little actual information or definite data are available.

Piston-Ring Friction

First considering friction, it has been said that "friction is the highway robber of mechanical energy." I often think it is the highway robber of gas-engine efficiency. Nowhere is this more clearly illustrated than in poorly-machined cylinders and poorly-fitted pistons and rings. It was necessary 20 to 25 years ago to run an engine with a belt for several days to get it limbered up enough so that, assisted by a heavy flywheel, it would start and keep moving from one explosion to another. Today, thanks to improved machine tools, we can start

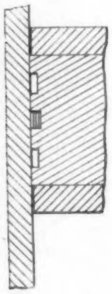


Fig. 5

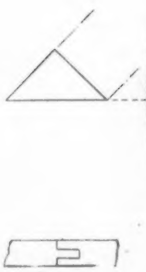


Fig. 6

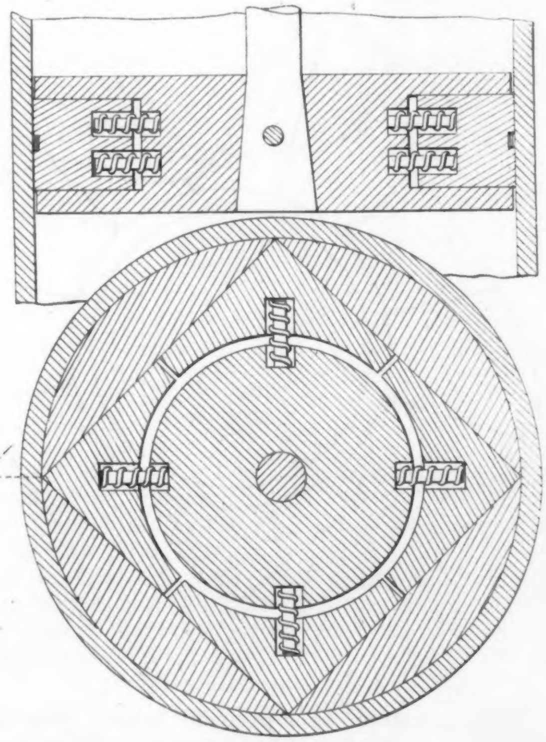


Fig. 4

engines working immediately after they are assembled. Still we know from experience that the power improves for some time even with almost perfectly-machined cylinders, until the cylinders, pistons and piston-rings have acquired the mirror-like polish taken on by cast iron under proper conditions.

Few actual data are available regarding losses due to friction of the piston-rings alone, but the mechanical efficiency of a gas engine is generally from 75 to 90 per cent. In the mechanical losses we include the pumping losses, which amount to about 33 per cent. The losses due to purely-mechanical-contact friction in average motor-car engines can be taken at about 10 to 12 per cent. Tests recorded in Germany showed that in some cases

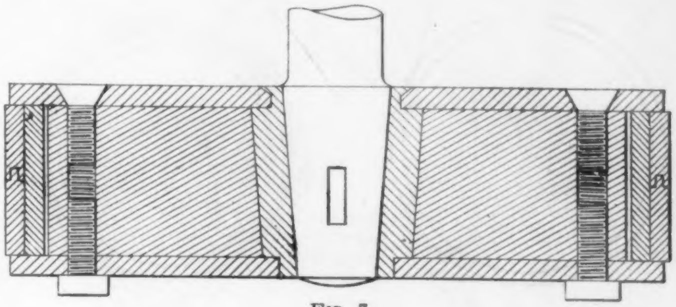


Fig. 7

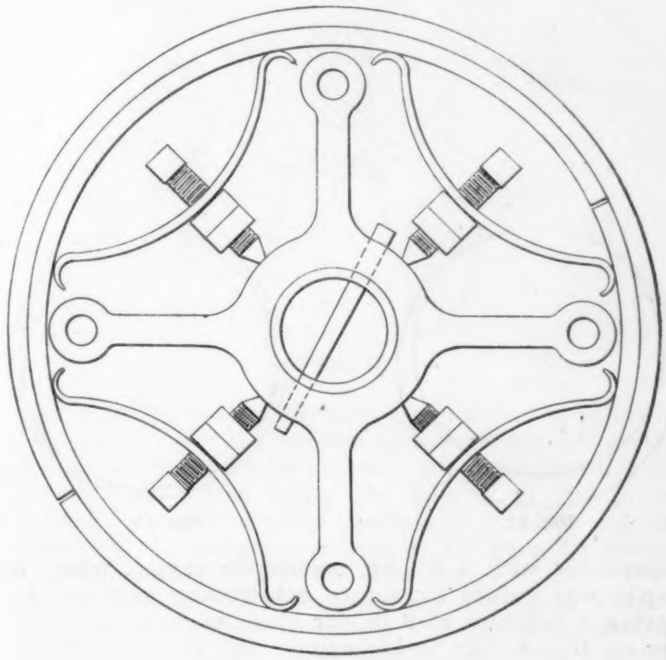


Fig. 8

the friction attributable directly to the rings was as high as 85 per cent of the total engine friction. This is high, I think, but the few cases I have observed and some data I have obtained indicate that the friction of the rings alone is about 70 to 75 per cent of the total engine friction when running under light loads. Under heavy loads the percentage of ring friction is probably only about one-half of this amount.

In his Notes on Piston-Rings in the *Automobile Engineer* for October, 1916, Gwilyn Williams mentions an

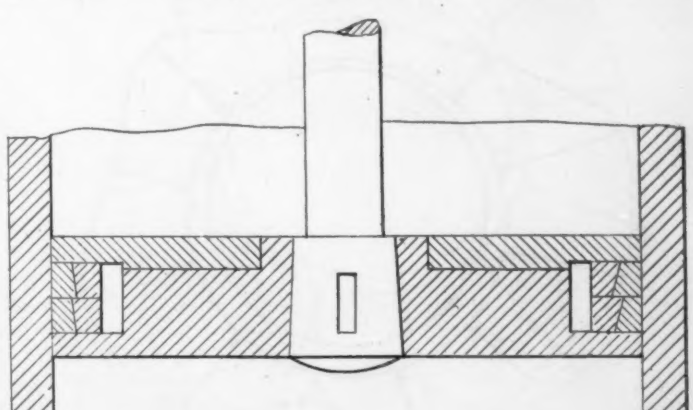


Fig. 9

FIG. 10

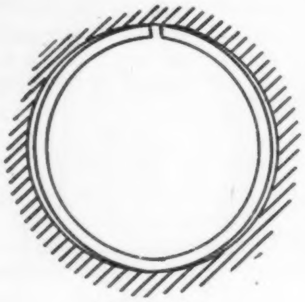


FIG. 11

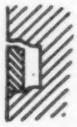


FIG. 13

FIG. 12

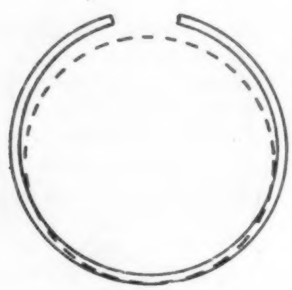


FIG. 14

experiment with a 3½-hp. motorcycle engine, where 5 m.p.h. was gained by simply substituting piston-rings having a pressure of 8 lb. for rings of 11-lb. pressure per sq. in. A friction-horsepower test of an American aviation engine showed that, with all three rings in each piston in action, it required 39.2 hp. to keep it moving at 1200 r.p.m. With one ring removed from each piston, it only required 26.6 hp. to operate it at the same speed. The ring friction alone was computed to be 73½ per cent of the total mechanical losses. According to another source of high authority, the friction loss in the average aviation engine is about 13 per cent under normal conditions, about one-half of which is due to the pistons and rings. All this tends to prove the great importance of having proper piston-rings, especially with the present tendency toward more cylinders and high piston speeds.

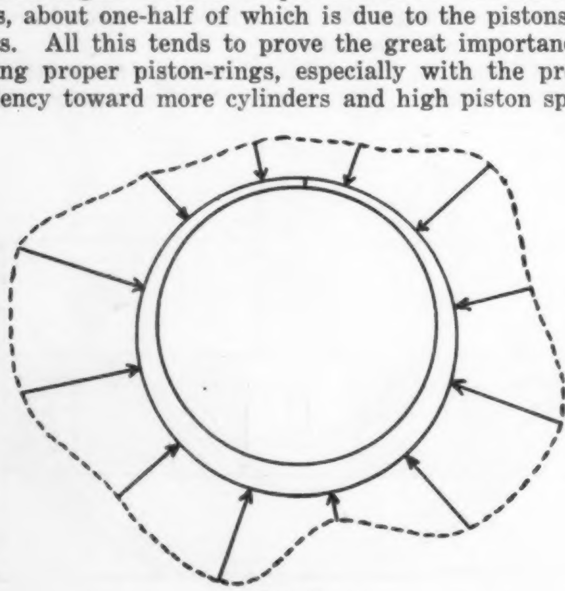


FIG. 15

It should be remembered that the engine is running at full load only about 5 per cent of the time in the ordinary motor car. The piston-rings, however, are exerting their full pressure against the cylinder walls whether the engine is running at full load or is simply idling.

The lightest permissible pressure exerted by the rings against the cylinder walls means a minimum amount of friction. This pressure must be uniformly distributed around the entire circumference of the ring; that is, there must be a uniform radial pressure against the cylinder walls. How to obtain this has been and is today a most difficult and intricate problem in the design and manufacture of piston-rings. Practically all machine tools are designed for cutting either straight or circular lines or surfaces. As a matter of fact, a piston-ring exerting a uniform radial pressure against the cylinder wall, when in the free or expanded state, is neither circular, elliptic nor parabolic. Its curve has not yet been named, but it bears the same relation to a circle as the parabola bears to a straight line. To finish-machine such curves directly and correctly has so far been a practical impossibility. That is why a ring is sprung together, clamped between discs and given the last finish-grinding to correspond with the bore of the cylinder for which it is intended.

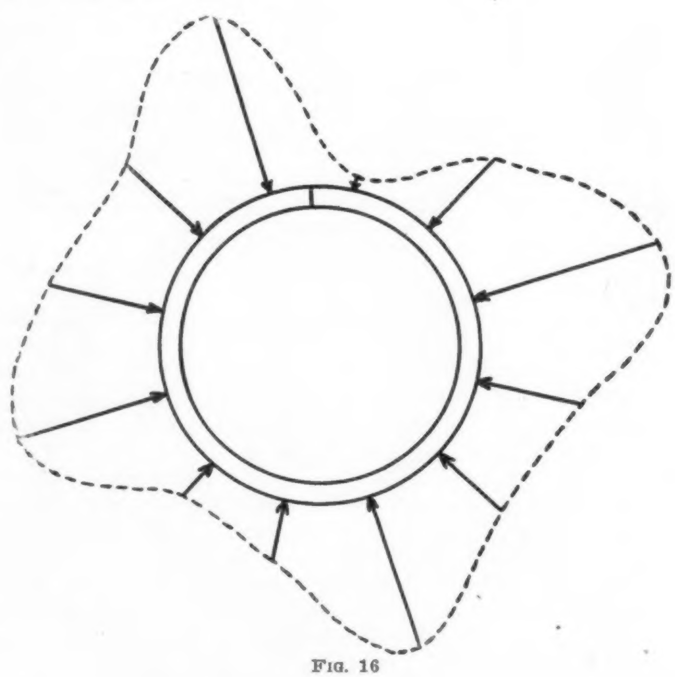


FIG. 16

To understand this problem better, consider the development of the modern piston-ring. When, for instance, a turned circular concentric ring with a portion cut out as shown in Fig. 10 is sprung into a cylinder, it will make contact only at the middle and at the points as shown in Fig. 11 because, when compressed, it does not remain circular. To overcome this difficulty, at least in part, some manufacturers even today make the ring blanks eccentric, of two circular curves, and then split the ring at the thinnest part. If such a ring is sprung together, clamped into position and given one or two finish-grindings, it may fit a circular bore. The pressure will not be uniform, however.

Piston-Ring Fitting and Pressures

To show how difficult it is to produce a perfectly fitting piston-ring, I mention the instructions given in Les

Secrets de Fabrication des Moteurs a Essence pour Motorcycles et Automobiles, by Georgia Knap, published in 1900. He shows eccentric rings but says they should be placed in a true cylinder which has been coated with bluing, moved about, taken out and have their high spots filed off until a perfect fit is produced. This is very much the same process as is used for scraping-in bearings. It can be said that this was the practice 20 years ago, but the Knap book is really very valuable and contains many points of detail not yet appreciated by many engineers. It accounts, however, for the superiority of the early French automobiles.

A uniform-pressure ring can be produced theoretically

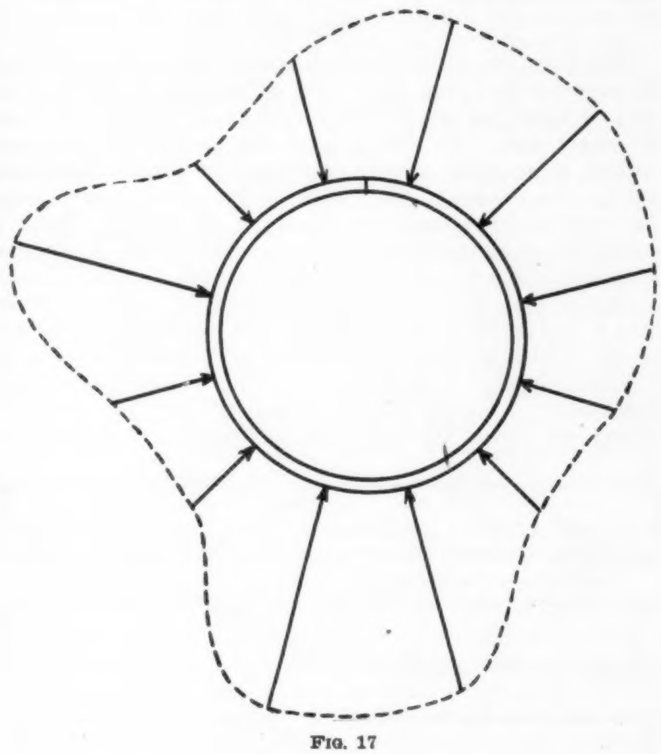


FIG. 17

in either eccentric or concentric form. An eccentric ring would, for instance, look something like the one shown in Fig. 12. In the middle the ring would be abnormally thick, and at the joint the inside and outside surfaces would meet in a sharp point. The tapering thickness of the ring would be such that only one of the curves could be circular; the other curve would be of that unnamed form already mentioned. Such a ring would be not only impractical to manufacture but of not much use because the grooves in the piston would need to be unnecessarily deep and the joint could not be made gas-tight.

In the days when gas-engine cylinders as well as piston-rings were made of ordinary soft cast iron, the rings, regardless of how they were made, sometimes lost their elasticity. It was common practice to take a so-called "dead" ring and peen the inside with a hammer until it expanded so that it could be used again. It was also understood that, because the piston is slightly smaller than the bore of the cylinder, the ring must be left floating and perfectly free to expand against the cylinder walls; but that at the same time it must have a perfect fit in the grooves of the piston. When an engine is running, there is a slight radial motion between the ring and the sides of the piston grooves which causes a small amount of wear. Experience shows that eccentric rings

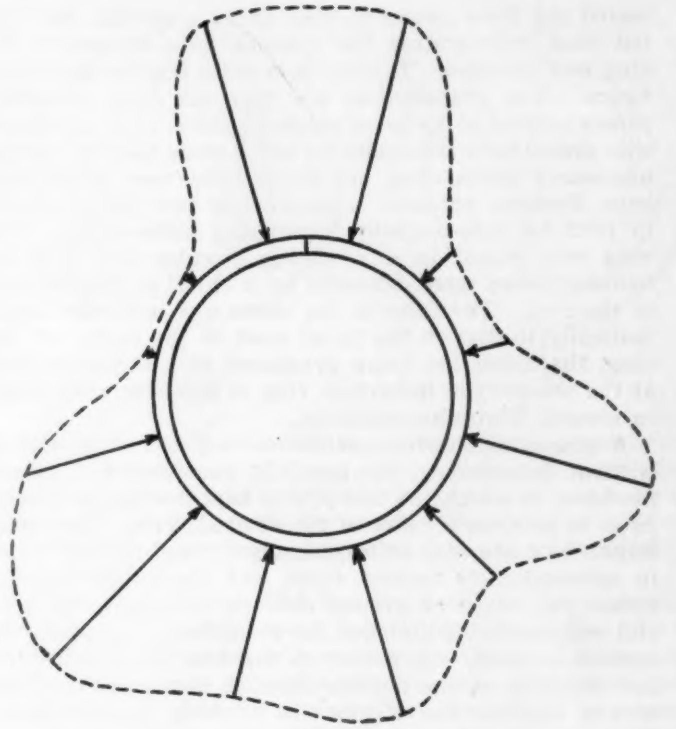


FIG. 18

will wear the piston grooves, somewhat as is shown in Fig. 13. With this knowledge the natural suggestion would be to construct a ring of uniform thickness throughout, nearly filling the grooves of the piston, getting as much wearing surface as possible and also lessening the chance of leakage of the gases by passing behind the ring.

The evolution of manufacturing a ring of uniform thickness having approximately uniform radial pressure against the cylinder wall came about in the following manner. Circular blanks of equal thickness were turned up slightly larger in diameter than the cylinder bores they were intended for; they were then parted, usually with a diagonal cut. The ring blank was then expanded by hand-hammering on the inner surface until it approxi-

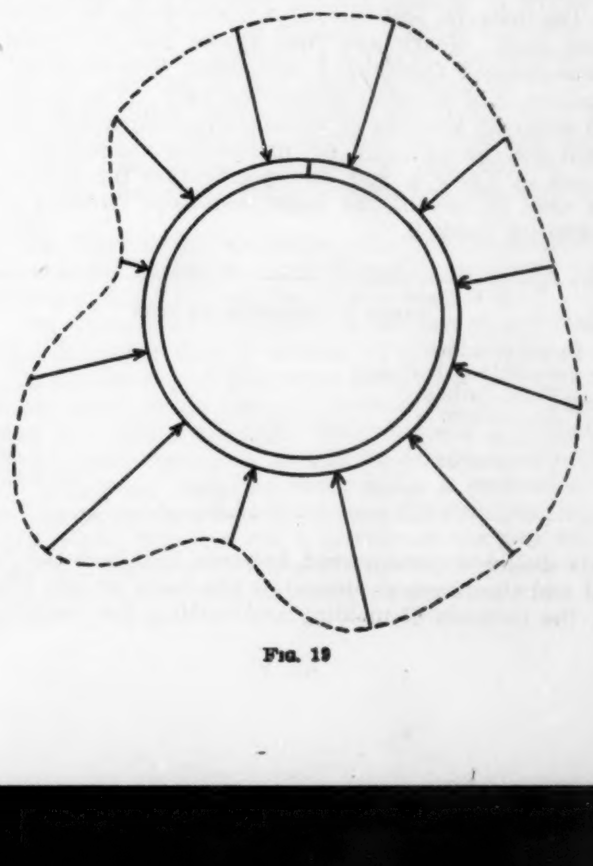


FIG. 19

mated the form shown in Fig. 14 on page 528, the dotted lines representing the circular bore for which the ring was intended. This curve is not a regular geometric figure. The probabilities are that the early manufacturers arrived at its form experimentally. I do not know who should have the credit for originating the commercial hammered piston-ring, but Davy Robertson of Gothenberg, Sweden, patented a machine in the United States in 1902 for automatically hammering piston-rings. The ring was placed in a revolving circular die, and the hammer-blows were delivered by a chisel to the interior of the ring. The force of the blows was controlled automatically to distort the metal most at the center of the ring, the distortion being graduated to a minimum just at the joint. The Robertson ring is manufactured today in several European countries.

A concentric uniform-pressure ring can be produced without hammering, by specially constructed turning-machines in which the tool post is kept moving by a cam, so as to produce a curve of the desired form. The rings might be made also from specially formed patterns cast in approximately correct form, and the inside surface either left rough or ground out approximately, the side and outside being finished by grinding; but, whatever method is used, experience so far has shown that the last finishing on the outside must be done with the ring sprung together and clamped in a nearly circular form. The correct form of a curve such as is shown in Fig. 14 on page 528 can be calculated, but manufacturing it is not so easy. The least variation in the temper and density of the iron will affect its elasticity so that, although a ring when sprung into a gage may fit perfectly enough around its entire periphery to prevent light from showing through, it may still exert an uneven pressure against the cylinder wall. Figs. 15 to 19 on pages 528 and 529 are diagrams showing the radial pressure exerted by rings of different manufacture. The length of the arrows indicates the proportional pressure at the particular point. Fig. 15 is an eccentric ring. Figs. 16 to 19 are concentric rings. These rings were all picked up at random in the open market. They fitted the gages perfectly and passed the "light test."

Piston-Ring Material

The material best suited for piston-rings is undoubtedly cast iron. Nearly everyone agrees that it should be a close-grained fairly-hard cast iron. The chemical composition and physical properties vary. The average of 10 different analyses of satisfactory iron which has been used for piston-rings by piston-ring manufacturers is given in Table 1, and the specification for piston-rings as used by one of the large motor-car builders is presented in Table 2.

TABLE 1—PISTON-RING IRON

Constituents	Per cent
Combined carbon	0.39
Total carbon	3.28
Manganese	0.59
Silicon	2.42
Phosphorus	0.52
Sulphur	0.95

TABLE 2—PISTON-RING SPECIFICATION

Constituents and Properties[2]	Per cent
Combined carbon	0.650
Total carbon	3.100
Manganese	0.400
Silicon	1.750
Phosphorus	0.350
Sulphur	0.075
Graphite	2.450

[2]Tensile strength, 34,500 lb. per sq. in.; elastic limit, 26,000 lb. per sq. in.; elongation in 2 in., 0.5 per cent; scleroscope hardness, 40.

It should be remembered, however, that both the chemical and the physical properties are more or less affected by the methods of molding and casting, the temperature of the iron at the time of pouring, the moisture of the sand and the like.

Joints

The question whether the diagonal cut or the step joint is superior has been discussed as long as I can remember. I think we are no nearer the solution than we were 20 years ago. As nearly as I can determine, the consensus of opinion among engineers of much experience favors the diagonal cut. I favor the diagonal-cut joint because of its simplicity and ease of fitting. With a concentric ring nearly filling the groove in the piston and a correctly fitted joint, lubricating oil will fill up the small openings and, due to capillary attraction, make as effective a seal as could be desired. The direction of the cut of the joints should, however, be arranged as shown in Fig. 20, because it tends to more even wear of the cylinder bore. A piston-ring is supposed to prevent lubricating oil from entering the combustion-chamber. A

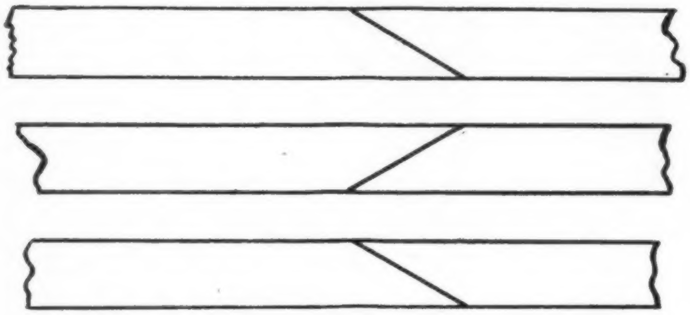


Fig. 20

piston-ring that will hold gas at several hundred pounds' pressure per square inch from getting past the sides of the piston, ought to be good enough to scrape the lubricating oil down toward the crankcase if given a chance, but it is not the function of the rings to do everything. The pistons should be designed so that the lower ring can force the surplus oil to the interior of the pistons or back to the crankcase.

Future Design

I have said little about the manufacturing considerations. That subject is covered in a general way in a number of textbooks. Each manufacturer has developed more or less special tools and appliances that are suitable for his particular requirements. As engineers, what we are really interested in is to establish some standard of what the properties of a piston-ring should be. The points that should be studied in particular include material, pot or individual castings, widths, style of joint, pressures, the number of rings per piston and the like. Some of the large manufacturers undoubtedly have data to satisfy themselves on these vital points, but I feel that

the time has arrived when we should be able to turn to the S. A. E. HANDBOOK and find some definite data on such subjects as what the average friction losses are in a four, six or eight-cylinder motor-car engine; how these losses are distributed and what the lowest permissible pressure is for the proper functioning of a piston-ring.

THE DISCUSSION

A. F. JACOBS:—What about the width of the 3/16-in. ring?

L. G. NILSON:—There is a great difference of opinion. A ring should be as narrow as possible, considering strength and wear. The life of a ring depends upon the material it is made of, wall pressure, smoothness of cylinder wall and lubrication. Actual life can be determined only by experience. Some manufacturers, especially of old-type engines, have been in the habit of having very wide rings. I prefer a narrow ring.

W. R. PETZE:—Does Mr. Nilson prefer a ring that is ground or one that is turned?

MR. NILSON:—The method of manufacture should not be considered if the article produced is up to standard. The hard close-grained iron of which piston-rings should be made cannot be finished to a smooth surface by turning. I therefore prefer a ring finished by grinding.

A. L. CLAYDEN:—What are the maximum and minimum pressures in the best rings Mr. Nilson has tested?

MR. NILSON:—The average of a good ring will run about 4 lb. per sq. in. I have never tested a ring that had absolutely equal pressure around the entire circumference. A perfect ring should have equal pressure all the way around. A good ring ought not to vary over 25 per cent, but we often find rings that have no pressure at some point, perhaps not even touching the cylinder wall, but that exert a pressure of 12 to 14 lb. per sq. in. at some other point. We might take a perfectly circular disc, Fig. 21, split it into halves, fasten the halves together with a hinge *a* at one edge, and arrange a compression spring *s* for forcing them apart. This device, sprung into a true cylinder, could be of a perfect fit and even stand the light test, but it would exert no pressure against the cylinder wall except in the direction of the arrows at *b*. If used as piston packing, it would wear the cylinder out-of-round. Incorrectly designed piston-rings will do the same thing.

C. E. DAVIS:—Mr. Nilson states that the basic principle of a ring moving in a true cylinder is to prevent the passing of gases by the piston. With a concentric ring, or with a ring with a diagonal cut, this cannot be done. The gases and oil cannot be prevented from passing the ring. If there is a pin-hole in the *crankcase*, the oil squirts through it and will go through in a solid stream. In my opinion, there is only one way to stop the gas from passing the piston-ring and that is to double-seal it against the cylinder wall and against the groove in the piston. From six months to a year's time is required to season the iron for a piston-ring. All the particles of the material must be allowed to take a uniform position. If that is not done, the ring will never be satisfactory.

R. L. SCHAAP:—Too much emphasis cannot be laid upon the fact that a ring should be made with as little wall pressure as possible, not only in regard to the pressure itself but in regard to the width of the ring. Width has a tendency to produce more wall pressure. We have made rings as large as 3⅛ in. in diameter with a pressure as light as 1½ lb. per sq. in. It is surprising how much more power can be generated in an engine having reduced wall friction. I speak from experience. We have made rings for engines running at more than 3600 r.p.m. We find that a ½ lb. per sq. in. pressure in a ring will hold down the speed. The circulation of oil around the ring keeps both the ring and piston cool to some degree.

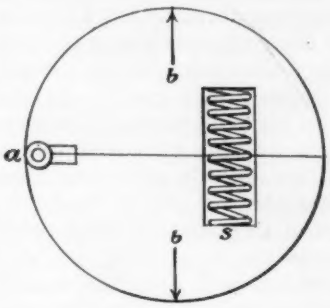


FIG. 21

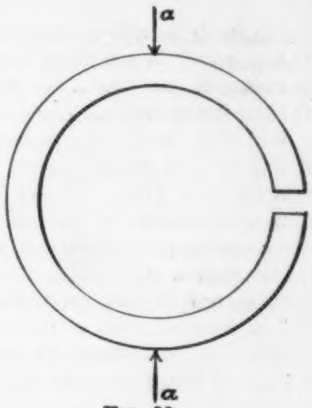


FIG. 22

CHAIRMAN A. M. WOLF:—The problem of piston-rings is interlocked with many other problems. The piston design and material have much to do with it. Carburetion has much to do with the effectiveness of a piston-ring, depending upon the state of the fuel when introduced into the combustion-chamber. Again, the effectiveness of the lubricating system is a matter in which the rings must cooperate. The ring is one of those very small details which seems to have had as much thought expended upon it as its relative size to the rest of the engine. To cope properly with the fuel problem of to-day it is essential that more thought be given to this extremely important detail.

J. E. DIAMOND:—I am impressed by what Mr. Nilson said about the narrow ring. I believe that rings will be made as thin as the manufacturer can machine the ring groove. Regarding oil that passes the rings and gas that enters the crankcase, that is especially true with the alloy piston-ring; there is more or less trouble due to the wear of the ring in the ring groove. I think we must have a narrower ring if we use alloy pistons. The same thing applies to iron pistons. The manufacturers have much trouble with pistons, mainly in winter, due to oil flowing from the cylinder. There has been much trouble with iron pistons in some of the highest-grade cars, on account of gas passing the ring. The ring groove, I believe, rather than the gap, is the main source of the trouble. The area between the ring and the band is much greater than the area of the gap; so, we will soon find that every manufacturer will use very narrow rings.

MR. DAVIS:—In connection with the circulation of oil around the piston to keep it cool, how about the circulation of gas around the ring to keep it hot?

MR. DIAMOND:—I believe in the use of one ring in a groove, rather than a number of rings.

P. M. HELDT:—I gave some thought to this ring proposition some years ago. I reached the same conclusion that Mr. Nilson reached. To produce a ring that gives a uniform pressure all around we cannot make a circular or cylindrical ring, we must make a cam ring. That is due to the fact that if we turn the ring circular in the first place, then cut out a portion at the gap and apply uniform pressure all around, naturally the ring will bend much more at a point opposite the gap than near the gap.

In fact, it will not bend at all immediately adjacent to the gap. If we turn the ring to a diameter of 4 in., for instance, cut out a section at the gap and then apply uniform pressure all around, the radius adjacent to the gap will still be 2 in., whereas, opposite the gap, it may be 1⅞ or 1 5/16 in. That is the way of gaging the curvature of a ring. If we have a circular ring, the radius will of course be the same all around. In case a uniform pressure is applied all around the outside of the ring, the radius will differ from point to point, but each small section will have a definite radius.

I worked out a formula which will give the radius from the cut right to the middle point, that is, for one-half of the ring; the other half, of course, is a duplicate of this.

$$r_1 = Et^3r - 60\ tr^3 \sin^2 \tfrac{1}{2}\triangle / Et^3 - (2r - t)\ 60\ r^2 \sin^2 \tfrac{1}{2}\triangle$$

where

- r_1 = the outside radius of any section of the ring
- r = the radius of the cylinder bore
- E = the modulus of elasticity of the ring material
- t = the radial depth of the ring, which is uniform all around
- $\triangle$ = the angular distance from the gap

For a 4-in.-bore ring, the radius r_1 figures out to 2 in., adjacent to the gap, and to 2.0618 in. directly opposite the gap; for $t = 0.126$ in. and $E = 15,000,000$ lb. per sq. in.

I was thinking at that time of turning the ring to cam form, cutting out a section, compressing it and finally grinding it, thus taking off a few thousandths of an inch.

How to measure the pressure is of interest also. Some speak of ½ lb., others of 4 to 5 lb., and Mr. Nilson mentioned 11 lb. per sq. in. I believe it is not possible to get as high a pressure as 11 lb. per sq. in. in a ring which must be fitted into its groove by expanding it and then pressing it together. The ring will break. To get so high a pressure we must have some more flexible material than cast iron. I think 6 or 7 lb. per sq. in. is about the limit. So far as I know, there is really no method of measuring the pressure of a ring. What comes nearest to it is to compress the ring by radial forces applied at opposite points 90 deg. from the gap. The pressure per square inch will then be substantially equal to the pressure required on one side to close up the ring, divided by the width of the ring.

MR. NILSON:—My experience is that if it takes a pressure of say 10 lb. per sq. in. applied on opposite sides, as at *a* in Fig. 22 on page 531, to bring the points of the ring together, that particular ring would exert an average pressure of about 3 lb. per lineal inch if sprung into the cylinder it is intended for. If that ring were ¼ in. wide, that would of course mean a pressure of 12 lb. per sq. in.

MR. SCHAAP:—What if a wire were brought around the ring and the ends pulled together?

MR. NILSON:—That is a different proposition. The ring would bend mostly in the middle and would not require much pull. The reason the pressure per inch is greater is that the diameter of the ring is larger in every direction than the cylinder it is intended for; so, it must bend all over when sprung in place. When I speak of pressure, I mean the actual contact pressure that every portion of the ring periphery exerts against its share of the cylinder wall. Calculations of this pressure are complicated. John Prescott had an article on The Bending of Thin Rings in the September, 1919, issue of *The Automobile Engineer*, which resulted from an investigation having special reference to the behavior of piston-rings under radial pressures. It describes the computations. They were too complicated for me, so I built a machine to measure the pressure direct.

MR. CLAYDEN:—Has anyone made tests of rings of different width in the same type of engine? I had experience with narrow rings in the airplane service. Under certain conditions they undoubtedly increased cylinder-wall wear.

M. C. HORINE:—I am familiar with some experience with wide and narrow rings which is somewhat contrary to the impression that a narrow ring necessarily means more cylinder wear. We must consider the ring as a knife, cutting a film of oil on the cylinder wall. We want a slight film there, but we do not want too much. We need not oil the combustion-chamber. The sharper the knife, the less pressure it requires to make it cut. Consequently, if the ring is made narrower we can get along with less total pressure, which means about the same pressure per square inch. In other words, it takes a certain pressure per square inch to penetrate this film. The fewer square inches we have, the less total pressure we need.

I can see no reason why we cannot design a narrow ring that will give the same pressure per square inch as a wide ring. My experience was with a piston in a motor-truck engine. Formerly three rings were used, two of them being conventional one-piece concentric rings. The third ring was a three-piece ring and very wide. To cut the film of oil with that ring, great pressure was necessary. It was an outer ring backed up with two inner rings with over-lapping joints. The theory is that the joints were the cause of leakage and that with a wide-enough ring and overlapping joints leakage would be avoided. The result was abnormal cylinder wear. Substituting four rings similar to the other two reduced cylinder wear, made lighter pistons and resulted in slightly more power. This amounts to reducing the total pressure of the ring because of its smaller area.

With narrow rings, most of the wear on the piston comes on the side of the groove. Obviously the lighter ring, the ring with less pressure, should move less than the wider ring. That is because the ring cocks in the cylinder each time it reciprocates. The ring which is in a narrower groove has a greater guiding surface on the horizontal portions of the groove than a wider ring; consequently, it should cock less. Perhaps we need deeper rings and grooves. With an eccentric ring, it is possible to have one portion very deep. Perhaps if we make the ring narrower and somewhat deeper, it will produce less piston and cylinder wear.

Regarding ring gap, the popular impression is that the gap is the cause of ring leakage. That is why buyers are so anxious to get a gapless ring, or a ring whose gap is sealed by multiple rings, or something of the sort. Much attention is paid to placing the rings in the piston so that the gaps do not line up. Fig. 20 in Mr. Nilson's paper showed the diagonal cut reversed in the middle; likewise at the top and bottom. I am under the impression that most of the leakage on pistons is due to either rings that are not round and therefore bridge, or rings that are poorly fitted and therefore bridge. How serious is this problem of gap leakage?

MR. NILSON:—The small gap at the joint of a properly fitted ring is insignificant, whether it is of step-joint or diagonally-cut type. Figured in square inches it amounts to practically nothing. Those who have had any experi-

ence with capillary attraction know that it is very powerful. An engine cannot run dry; there must be some lubricating oil. If there is no excessive gap at the joint, the little opening will be filled with oil and form a perfect seal. I am now referring to concentric rings which nearly fill the groove and have surfaces large enough at the joint to give capillary action a chance. Eccentric rings, being thin at the joint, do not afford sufficient surface for the oil to cling to; therefore, leakage is caused by the gas pressure blowing the oil out of the joint and by-passing in the idle space under the ring.

NEIL MACCOULL:—The piston and piston-ring are important in connection with the lubrication of a gasoline engine. It is obvious that oil which enters the combustion-chambers must pass around the ring somewhere. According to some theories no oil should pass the ring "because there is a perfect seal," but it does enter the combustion-chambers. I must acknowledge that we do not know how it enters, although I can see many probabilities. I have never heard of an engine in which oil did not enter the combustion-chamber, and neither have I heard of one in which the gases never passed the piston-rings and entered the crankcase. As proof of this, in practically every dynamometer test or whenever an engine is in operation, a continuous stream of gases comes out of the breather-tube. I contend that much of that gas must have leaked past the piston-rings; therefore, so far as I know, there has never been a case of a perfectly fitting piston-ring.

MR. NILSON:—If an engine with plenty of lubricating oil in the crankcase is run at a high speed by a belt, with valves and spark-plugs removed, what appears like gas or smoke will come out of the breather tube, although there is no fire in the combustion-chamber.

MR. MACCOULL:—I rather expected that contention. Of course, the air in the crankcase will expand as the lubricating oil warms up, because of the heat of friction. Therefore, it expands and passes out until a stable temperature is reached. Furthermore, on a four or an eight-cylinder engine, the volume of the crankcase varies with the rotative speed of the engine, because of the angularity of the connecting-rods. This does not exist in a six-cylinder engine. The dynamometer tests I mentioned were made with a six-cylinder engine and, after being continued long enough for the temperature to become uniform, still indicated a continuous stream of vapor coming out, which I am positive would not be the case with the belted-in engine.

MR. NILSON:—To explain this differently, the atmosphere is never perfectly clear except after a rain. Much of the haziness we see is dust. Dust is composed of both organic and inorganic matter; all of it is heavier than air and some is heavier than water; it is pounded up so fine that it almost approaches the molecular state. When the particles become so small that the cubical content or weight is insignificant compared with the surface exposed, they will float around in the air indefinitely. The same thing applies to oil. Oil is of lower specific gravity than dust. The moving parts in the crankcase churn up the oil until some particles become small enough to float out through the breather-tube. It may look like smoke, but is simply pulverized oil. The carbureter people should consider this and make use of it.

MR. SCHAAP:—To what extent does capillary attraction take place in the ring-gap?

MR. NILSON:—If sticky oil is put upon a clean surface, it is difficult to wipe it off. When water is put into a glass that is not greasy, its surface at the edge has a slight upward curve or fillet. If two surfaces are close enough together so that the two fillets join, there is capillary action as in a tube. The opening at the joint of a piston-ring is so small that the explosion should not blow the oil out on a high-speed engine.

MR. SCHAAP:—Has the thought of using the joint as a capillary pump been considered, keeping a circulation of oil at the joint?

VICTOR W. PAGÉ:—A ring that does not have much metal will lose its elasticity. How narrow can a ring be made and still remain structurally strong for use on a piston?

MR. NILSON:—I cannot answer that question.

MR. PAGÉ:—Some experiments were made a few years ago with air-cooled rings. I had considerable trouble with narrow rings made of cast iron. We substituted steel rings and cured the trouble so far as the breaking of the rings in service was concerned, but encountered more trouble regarding cylinder wear.

MR. SCHAAP:—Tremendous wall pressure is required on a very small ring, but not on every ring. The rings that we used exerted about a 1½-lb. pressure. We measured the ring by putting a very fine wire around it and closing it. We do not depend upon mechanical tension. Should a ring have its own mechanical tension or should it depend upon other means for holding it against the cylinder wall?

O. P. SELLS:—Does not the basis of the fault lie in the cross-section, or the strength of the ring to withstand the load? What is the load the ring must carry? It should be determined. How does the ring carry this load? Is the leakage between the ring and the cylinder wall, or over and under the ring? Taken in connection with the cross-section, it should be determined whether the ring should be narrow, thick, thin, of cast iron or steel, with heavy or light pressure.

CHARLES R. MANES:—In Fig. 13 of Mr. Nilson's paper, the end of the eccentric ring which had greatly worn the groove of the piston is shown. It is perfectly clear that trouble would be caused by leakage back of that ring. All manufacturers would turn out a very fair engine with a plain ring properly fitted but, almost universally, after those cars have been driven from 3000 to 5000 miles, they begin to pump oil. My experience in service work shows that the narrower the ring is, the more of an oil-pumper it becomes. I attribute that to the excessive wear of the ring and the groove lands. Those groove lands can be ground out and, in some cases, the grooves can be deepened and a ring put in with a larger wearing area. A greater mileage with less oil pumping than with the engine when new can be obtained in that way. I believe that many service men will bear me out in the statement that what we need is deeper grooves and a larger wearing area. I think the matter of light wall pressure does not amount to much. I agree that with less wall pressure we obtain more power, less heat and a longer cylinder life. I believe that with deeper grooves and larger wearing areas on the rings against the groove lands, we will obtain a longer life without tearing the engine down and putting in new rings. It is true also that the ring will stand up longer and show less tendency to break, particularly the rings that are in the top groove.

MR. HELDT:—Does not Mr. Manes mean wider grooves?

MR. MANES:—Deeper.

MR. HELDT:—I do not understand how that affects it.

MR. MANES:—The effect is in a radial direction. To function properly in a groove, the piston-ring must have

room for expansion and lubrication; otherwise, it will stick. From the moment the ring is installed until it gets heated so that it will not reciprocate, there is a reciprocating motion of that ring in the groove which gradually increases, particularly in a high-speed engine. The piston consequently becomes a reciprocating pump. If we start the piston from the explosion stroke, as it goes down the ring is wiping the oil under the ring with whatever gap there may be there; as it comes up, the ring is forced to the bottom of the groove and, as the oil must pass somewhere, it passes back of the ring toward the top. When the piston starts downward again, there is a partial vacuum above it in the cylinder; otherwise, the charge would not be obstructed. That partial vacuum is also drawing the oil toward the top and, when the piston comes up on the compression stroke, it is pushing the oil ahead. When the ring gaps become great enough, we begin to have ignition trouble, missing cylinders and an oil-pumping engine.

THOMAS G. SAXTON:—I think that the ring depth has nothing to do with it. The ring is nothing more or less than a check-valve. The best check-valve today is a spring check. A piston-ring instead of checking on both sides of the groove should check only on one side.

MR. MANES:—On an old 4½-in. engine, I found recently that the clearance of the ring groove was exactly 0.039 in. One can judge whether there would be a passing of gas or oil back of that ring. The grooves were turned out and fitted with good rings. There was no further trouble with the engine.

MR. SCHAAP:—I referred to the heavier ring. It is obvious that a ring should be made as light as possible.

ROBERT E. EHRLICHMAN:—I will not attempt to offer a panacea for all piston-ring ills. I will give you the benefit of what we have been asked to produce in piston-rings. The results have been satisfactory thus far. We are at a loss to know whether to make a wide ring, a narrow ring, a thick ring or a thin ring. Only within the last few years, since 6 and 12-cylinder engines have been built, do we find a greater demand for a thin ring. about 3/16 in. wide. We believe that a piston-ring is intended to take up the clearance between a piston and the cylinder wall and to help lubricate both the piston and the cylinder. To accomplish this we must consider that the ring in itself is very small and, being much smaller than the cylinder wall, it will most naturally offer the least resistance and will therefore get the greatest amount of friction and wear. To prevent friction, we must use oil. To use oil and use it constantly, keeping it there by a steady flow of some mechanical certainty, a carrier must be provided for that oil and we must provide it in the ring itself. How to provide that carrier depends entirely upon ideas of design. We have designed in our ring an oil groove that will lubricate the ring itself as well as the cylinder wall, at the greatest number of points possible. We believe that on the upstroke this groove will carry a certain amount of oil to lubricate itself and the cylinder wall, and that on the down stroke it will scrape off the excess oil and send it into the crankcase again to be used for lubrication. We believe further that the construction of our groove will prevent the groove from filling with carbon, because it is natural that the carbon will not remain in the groove if it is cut in the ring on an incline. Our experience proves that our theories are correct. I am presenting them for what they are worth.

FREDERICK RAY:—Some years ago I worked out a method of measuring pressure by a scale or balance and pressure applied opposite. I found that, if the ring is considered as giving uniform radial pressure, the pressure per unit length of the circumference of the ring is equal to the concentrated load at the top, which is equal to the reading of the scale or balance divided by 2.27 times the radius. That gives the pressure per linear inch. The pressure per square inch is obtained by dividing that result by the width of the ring, assuming that the ring gives uniform pressure. The method is to apply a load to the top while the bottom rests on a spring-balance, until the distance across in the direction of the load is equal to the normal diameter of the ring, the cut in the ring being at right angles to the direction of the load. The method of compressing the ring until the two points meet has been used by some, but it gives the wrong result because the curvature at the end of the ring is different from what it is when the ring is compressed in the cylinder. When compressed so that the diameter across in the direction of the load is equal to the normal diameter, the results I have stated are obtained.

A MEMBER:—There seems a wide diversity of opinion regarding what a piston-ring ought to do. What the public would like to know is how long a ring will last and when new ones are needed.

FRED KELLER, JR.:—With a three-ring piston and the gap lined up, why does crankcase dilution occur and why are the combustion-chambers filled with oil?

MR. NILSON:—Rings having a diagonal cut in the same direction have a habit of lining up so that the joints are all in line. With rings cut in opposite directions, there is a slight propeller action. They are perfectly free to crawl around, thus mixing-up the position of the joints, and they produce more even wear on both the ring and the cylinder. I am not prepared to give the exact reason, but that seems to be the experience of service men. Practically all designers agree that the middle ring should be cut in the opposite direction.

MR. SAXTON:—I have made rings of all kinds. We used to pin the rings in. On a modern engine it is practically impossible to pin the ring in. First, the manufacturer would not stand the cost. A piston-ring should be flexible enough to fit a cylinder that has worn irregularly. The present snap ring is two rigid to obtain this result even though it may be ground perfectly. Is not the problem to get a ring that will fit a distorted cylinder?

MR. NILSON:—No. I never considered trying to make rings to fit all kinds of cylinder. One of the conditions for making a perfect ring is that it is to run in a reasonably good cylinder. In the old days of the steam engine it was perfectly proper to pin the rings and keep them in one position. In time they would wear so that the rings and the cylinder fitted together and gave fairly good results. With a steam engine it makes little difference so long as there is plenty of boiler power but with a gasoline engine it is different. Each explosion must produce enough power to keep the machine going until the next cylinder gets a chance. There might be emergency cases where we would resort to almost any scheme, but that is not engineering. For standardization work we should consider only good rings and good cylinders.

MR. SAXTON:—Steam engineers should be and are as particular as gas engineers regarding the circumferential fit of the ring and its fit in the piston grooves. A snug-fitting piston-ring will create a vacuum and not pump oil.

MR. NILSON:—A steam engine will work fairly well with almost any kind of a ring, or no rings at all, if there is plenty of boiler capacity.

MR. MANES:—Very few modern pistons have sufficient body to hold the pin to line up the piston-rings.

MR. SELLS:—Why is it desired to pin a ring?

MR. SAXTON:—In a two-cycle engine the rings must be pinned to prevent the openings of the rings from entering the gas ports.

MR. SELLS:—Is it not the pressure of the passing gas that causes the ring to turn?

MR. SAXTON:—When the ring is sliding in a groove, is it not reasonable to suppose that it is turning around also?

MR. HORINE:—This problem of pinning a ring is very much like that of tying a tire chain. Formerly we tied the tire chain to a spoke so that it could not creep. The result was that a pattern of the cross chain was imprinted on the tire. Then we found we ought to let the chain creep. As Mr. Nilson has shown, no ring on the market exerts an equal pressure all around. If the ring is stationary, the cylinder therefore will wear more in one spot than in another and become distorted. Everyone knows that rings do creep if they are not pinned. That means equal distribution of wear. Pinning rings is not practicable because the pins will come out. They are very difficult to fit. There is not enough body in the ring to hold the pin.

Another cause of cylinder distortion is bad cylinders. A cylinder that will become distorted after it has been in use has not been properly aged or heat-treated. It is perfectly fair on the part of the piston-ring manufacturer to ask the engine builder to give him good cylinders. No reasonable man can expect a round ring to fit a distorted cylinder. We ought to start with the idea that we will have a good cylinder and not a distorted mass of metal.

Mr. Nilson answered the question as to why gas will not go down through the gaps. It is simply a matter of proper end-clearance on the ring. If this is right, the ends cannot separate far enough to destroy the capillary action. If they are close enough together, and the closer they are together the greater the capillary action is, the resistance of the body of oil in that gap will prevent more oil from going through and prevent gas from going through. That is why I believe most of the leakage is through bridging of the ring, due to scored cylinders or rings which are not round, and not through the gap. Theoretically, it is impossible to have a round ring unless it is made cam-shaped. We can make them approximately round, however. I believe that the question is one of end-clearance, which depends upon good workmanship. When every garage is fitting piston-rings, we cannot expect to get proper end-clearance.

MR. MANES:—Cylinders become distorted in many different ways. One is by the improper fitting of piston-rings, fitting them too closely. If either a bevel-cut or a snap-cut piston-ring is fitted too closely, when it expands it will give. This is generally at the softest place in the cylinder wall, because the piston-ring that depends upon itself for its wall pressure is generally of harder material than the cylinder wall. The blame cannot all be laid upon the manufacturer, although we did have bad cylinders during the war because the manufacturers could not get material far enough ahead to season it. We are still suffering from that complaint.

The question was asked as to why the rings are not pinned. As long as a ring creeps it will never lap in, although on examination it will give the appearance of having lapped in; but while the ring is moving around in the groove in and out, it will never lap in. Several different types of ring are made, however, that neither creep nor reciprocate in the groove, and they do not need pinning for a two-cycle engine.

MR. DAVIS:—I do not agree with this idea of capillary action in the groove. The fact that there is a pressure of 250 lb. per sq. in. is sufficient to indicate that it will blow through. It will blow anything out of there. Therefore the ring will leak.

CHAIRMAN WOLF:—Have you figured the area of that groove space?

MR. DAVIS:—When the ring is put in, as soon as the cylinder gets hot that ring gets opened up. Consequently there is a gap in there. I have tried it out.

MR. HORINE:—Does not the ring get hot as the piston gets hot and expands, and does that not compensate? Also, we should not forget that we are depending upon the capillary action of the oil all the way around the ring. The idea that the ring is touching the cylinder is wrong. It is a physical impossibility to make any two bodies touch. Two sheets of glass can be placed so closely together that it is difficult to pull them apart, through no bond whatever but capillary attraction. It is a proved fact that often, with a bridging ring, we get a larger area of void between the ring and the cylinder on the plain side of the ring than the area of a diagonal-jointed ring with proper end-clearance.

MR. DAVIS:—If the ring does not touch the cylinder wall, how does it cause wear?

MR. HORINE:—Under a microscope, any metal surface is seen to be a series of teeth. Those teeth approach one another and knock each other off, and that is what the wear of metal is. The surfaces do not touch, but they approach, through an oil cushion in this instance.

CHAIRMAN WOLF:—It appears that the cylinders may be imperfect. Is that a negligible quantity or not? In some castings the cylinders are tangent to each other, coming together and touching without a water-jacket between. There is a tendency to distort. The changed diameter would be sufficient to allow a very small gap between the ring and the wall. Many cylinder blocks have an internally cast intake pipe that goes between two cylinders, tangent to the walls. There we have a cold intake pipe against a hot cylinder wall. At the bottom of the water-jacket and at various points where there is a wall or ribbing, there must be some distortion. Is that distortion to be considered infinitesimal?

MR. NILSON:—I think it is not infinitesimal, but we must remember that even the plain concentric snap-ring has a certain amount of elasticity. If the cylinder is slightly oval, the ring will tend to accommodate itself to it, but if it is too much distorted the ring cannot fit it. To obtain a perfectly uniform radial pressure, an absolutely circular cylinder is required. The rings will accommodate themselves considerably. In a cylinder that is worn to conical form, or irregular in shape, a snap-ring will do just as good or better work than some of the multiple rings, because, with the radial motion between the sides of the rings and the sides of the grooves of the piston, conditions are such that the friction will be less. If three rings with the openings in different places are put in the same groove and run back and forth in a conical cylinder, there is friction between the different portions of the ring. They act like brake-bands. On a high-speed engine the multiple ring has insufficient time to conform perfectly to a conical cylinder bore. The wear and the breakage of such rings are considerably higher than those of the plain rings.

A MEMBER:—If the cylinder is lifted off, the rings spaced equi-distant and the cylinder-head is set down, how is it that the oil-pumping stops?

MR. HORINE: — Probably the end-clearances were wrong. If the end-clearances were right, it would not pump oil in the first place.

J. W. LORD:—What is proper end-clearance? We have had statements of figures from 0.002 to 0.040 in.

MR. NILSON:—We have no accurate standard for end-clearance. The various types of engine cause it to differ. In some cases the temperature of the rings is probably higher than that of any other portion of the engine except the top of the piston-head. The ring has a slight extra temperature from the rubbing action against the cylinder.

C. M. BILLINGS:—Does oil-pumping mean a loss of power?

MR. NILSON:—I think it should not affect the power to any great extent. The power lost in shearing the oil film depends somewhat on the oil. It requires considerable power to keep a piston sliding with a film of thick oil between it and the cylinder wall. If the oil is comparatively light, the loss of power should not be great.

MR. LORD:—This matter of oil-pumping is a very serious one. Oil is expensive and excessive amounts make an engine unreliable. Full engine power may be developed so long as the ignition will function, but oil gums up the spark-plugs and valves. One of the first elements of engine design is to prevent excessive oil consumption. So far as cylinder wear and ring sizes are concerned, lubrication has great influence. Cylinder wear is something that cannot be determined within a short period. The elements that enter into it are uncertain, such as the quality of gasoline, the degree of crankcase dilution, piston-ring material and the like. There are also the hardness of the metal in the cylinders and rings and many other things that must be considered.

MR. EHRLICHMAN:—I wish to defend the one-piece ring. I designed a two-piece ring, but my experience with it taught me to return to the one-piece type. The experience was that in having two units I had two sorts of friction distribution that were never alike. When the rings came out for overhauling and were put back again into the piston, they did not function as at first. I believe that a one-piece ring will give the best results, do the work it is intended for and give satisfaction.

E. M. LORENZ:—Regarding properly-fitted rings, is there any consensus of opinion as to what the width should be? With a $3\frac{1}{2}$-in. cylinder, how closely should the ring fit?

MR. MANES:—The standard of groove clearance in a number of factories is from 0.0010 to 0.0015 in. side clearance.

DEPTH OF PLOWING

THERE is need for a large number of comprehensive investigations to furnish reliable information upon the relation of soil types to depth of plowing, energy expended and crop yields. There is information available to show that on our more common types of soil it is not desirable to plow over 8 in. deep for most crops, but experimental evidence is generally lacking in regard to results which can be obtained between the depths of 4 and 8 in. One California investigator with a national reputation summed up his opinions on the matter as follows:

> The depth of plowing in California is by no means constant, nor is it specific for any type of soil. Sometimes our heaviest soils are plowed to a depth of 14 to 18 in. as in sugar beet growing. Then again they will be most commonly plowed at a depth of 4 in. The same is true of light soils. We have no basis for believing that deep plowing is superior to shallow plowing. No experiment can be planned along this line which is not so full of errors as to make it practically worthless.

Contrasted with this opinion an investigator in Iowa wrote as follows:

> I am sure that, on the whole, plowing that is too shallow is practised in this State on practically all of our types of soil, with the possible exception of the sands. We usually recommend plowing 6 to 7 in. with observance of certain precautions such as not to plow a soil much deeper in the spring than has been the custom previously. We recommend that if the soil is to be plowed much deeper than in former years, the work should be done in the fall. We believe that the more general introduction and use of tractors will be a tremendously important factor in the deepening of plowing in this State. General practice of deeper plowing in Iowa should be productive of beneficial results and be noted in increased yields.

For purposes of discussion shallow, medium and deep plowing will be defined as follows:

Shallow plowing up to 5 in.
Medium plowing 5 to 8 in.
Deep plowing, 9 in. and deeper

Some years ago much was said about the advantages of plowing 12 in. or deeper. This stimulated a number of investigations on the subject. It would take more than an optimist to make a case for deep plowing in the face of the results. In only one instance, a two-year experiment in Utah, was there any marked increase in yields from deep plowing. There are some crops, such as sugar beets, potatoes and cabbage which appear to produce increased yields when planted on deeper plowed soils, although this conclusion is based on practical observation and not experimental evidence. For the ordinary crops such as corn, oats and wheat, plowing deeper than 8 in. is not recommended by men who are studying the problem, and their conclusions are amply supported.

The experimental evidence on the depths of plowing up to 8 in. is not comprehensive enough to warrant the drawing of general conclusions. The light sandy soils may be plowed shallower than the heavier soils. From 4 to 6 in. seems to be the range of depth best adapted to this type of soil. On the heavier soils it is desirable to plow to a depth of 7 in. and for this particular purpose the silts, loams and clays can be grouped in one class. It is advisable to plow deeper in the late summer and fall than in the spring. If the depth of plowing is to be increased it should be done gradually, not more than 1 in. each season.

There is a limited amount of experimental evidence, which is sustained by practical experience, to show that it may not be necessary to plow to the maximum depth every year to secure the maximum results. One successful farmer in Illinois plows to the maximum depth only once in three years. The work in Kansas furnishes data to support this practice. —E. A. White in *Farm Implement News*.

Battery-Ignition Systems

By J. H. HUNT[1]

CLEVELAND SECTION PAPER *Illustrated with* PHOTOGRAPHS AND DIAGRAMS

A BRIEF outline of the elementary principles of the operation of jump-spark ignition systems is a necessary preliminary to the discussion of the advantages of the so-called battery-type systems. The exact process of ignition is not definitely known. Tests have been made indicating that under certain conditions ignition may be caused by electrostatic stresses in the mixture, without the passage of a true current. Whatever may be possible when the mixture is in perfect proportions and at the right temperature, experience has shown the necessity of the flow of a certain minimum amount of current between the spark-plug electrodes, which means that heat is set free at the gap between the electrodes. It is very likely that the ignition is due to heating effect, and if the same amount of heat could be delivered at the same rate in the same limited space by other means, the ignition of the mixture would be equally good.

It is somewhat surprising to find that the energy is delivered to the spark at a rather high rate, at as great a rate as the rate of energy supply to a larger incandescent lamp than is used ordinarily for room illumination. This high rate of energy delivery lasts only a matter of millionths of a second. The passage of the current causes the gap resistance to decrease to a very small fraction of that existing before the discharge reducing the voltage required to maintain the current, so that the rate of energy discharge for the latter part of the spark is much less than the initial rate. It would be possible to construct and use a generator of electrical energy large enough to deliver the power required for the spark, and to arrange to connect this generator to the plugs in the proper way. If, however, energy can be stored up by a device absorbing power at a smaller rate and this energy can be abruptly delivered at a high rate, a smaller and more economical generator can be used.

We can consider the driving of a nail into a hardwood table as a very simple analogy. If the nail were driven by a steady pushing force, a power would have to be delivered at a higher rate than a man is capable of without the use of levers to reduce the speed and power rate. By taking a hammer and swinging it at the nail, energy is stored in the hammer at a rate we can conveniently supply. Due to the law of motion, one-half the mass multiplied by the square of the velocity, when the hammer strikes the nail this stored energy is delivered at a much higher rate than a man is capable of continuously, with the result that the nail is driven. In a similar manner we store up electromagnetic energy in preparation for the spark, and then deliver this energy at a very high rate relatively. In this way we can use a generator of small capacity for ignition instead of one of say 100-watts output.

There are four vital elements in a jump-spark ignition system, whether it is a battery or a magneto system. These are

(1) The source of energy which may be a battery in the battery system but, with modern systems when running, is the generator
(2) The device for storing energy which is the magnetic circuit of the coil with the interlinked primary winding
(3) A device for timing or releasing the energy which is the breaker mechanism and the condenser associated with it
(4) A device for transforming the potential of the released energy so that the spark will jump the gap under compression

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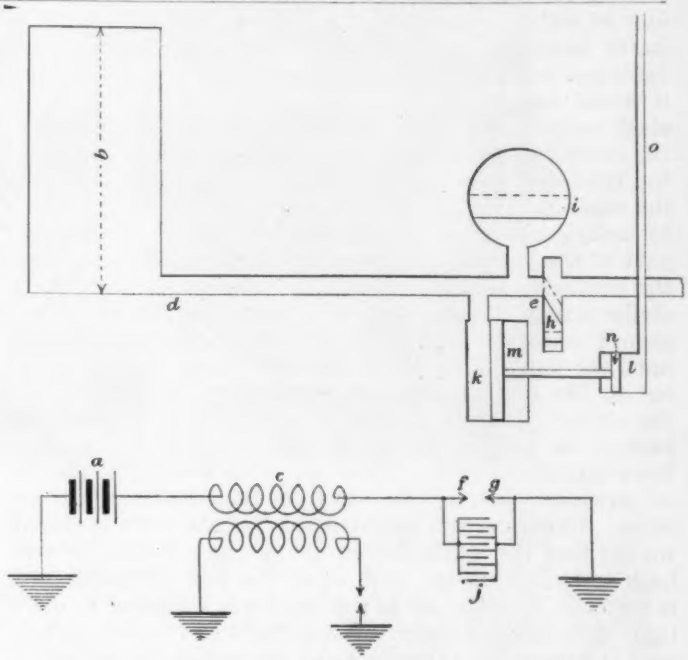

FIG. 1

Element (4) is present in the primary and secondary winding, interlinked with the magnetic circuit. This magnetic circuit and primary winding thus fulfil two functions in the ordinary ignition system. In certain low-tension magneto systems, the transforming device is entirely separate from the energy-storing device but, in the ordinary battery system and in the high-tension magneto, the same magnetic circuit that acts as a device for storing the energy is also a part of the transformer.

ELECTRIC AND HYDRAULIC ANALOGY

Fig. 1 shows diagrammatically the electrical circuits or system and above this an hydraulic system, which gives a fairly complete analogy to the electrical system. The source of energy *a* for the battery system is similar to the standpipe *b* of the hydraulic system. A direct-current generator of the same voltage as the battery in the first system would give the same results as the battery and, similarly, a centrifugal pump supplying water at the same head can be substituted for the standpipe. In the electrical system, the energy is stored in the inductance *c*, which consists of windings wrapped about a core of wire or thin sheet steel. In the hydraulic system the energy is stored in the moving column of water in the horizontal pipe *de*.

The electromagnetic energy stored in the coil *c* is released by the opening of the contacts *f g*, breaking the

current which previously maintained the magnetic field. In the hydraulic system is shown the slide valve *h* of rather peculiar construction to make the analogy more satisfactory. A slide valve has a thin forward edge and we will consider that this valve is made of tin or some weak metal. This is granted to be a very poor way to make a valve, but it is a good hydraulic analog of the best electric valve available. If the valve is closed against the flow of water in the pipe, the sudden rise of pressure, or water hammer, would break the thin edge of the weak valve and make it impossible to cut off the water quickly; it would also injure the valve. In a similar way in the electrical circuit the sudden rise of voltage at the separating contacts will cause an arc to strike across, prolonging the time during which the current dies out and burning the contacts. We can protect both of the defective valves by delaying the rise of pressure on them until the thick part of the hydraulic valve is across the opening, or until the contacts are so far separated that no arc is likely to strike across. An air dome *i* in the hydraulic system will permit water to flow in against the rising air pressure until the valve is closed, after which the water is forced out by the air pressure. A condenser *j* connected about the contacts absorbs electricity as the contacts open, and reduces the rate of current change. The electricity which flows into the condenser flows out with the fall of electrical pressure, just as the water is forced out of the air dome. Under certain conditions, after the valve is closed, we see that the water forced out of the air dome is sent back to the standpipe, and, when the flow is established, it may last until the air in the dome has expanded to more than its original volume. When the water starts to flow back it accumulates inertia and compresses the air, which later reverses the water flow and causes an oscillation in and out of the air dome, at one instant storing energy in the compressed air and at a later instant in the moving column of water. In a similar way energy can be stored in the electrically stressed dielectric, or insulation of the condenser, and sent back later as current which stores energy in the coil, the repetition of the cycle being an electric oscillation.

As an hydraulic analog of a transformer, we have two cylinders of different diameters, *k* and *l*, the large cylinder being connected directly into the horizontal discharge pipe *de*. When the valve closes, the rise of pressure set up by stopping the flow of water is exerted upon the piston *m*, which is rigidly connected with the smaller piston *n*. It will then be possible for the smaller piston to exert a much larger pressure per square inch of area against the liquid in the cylinder *l*, connected to the pipe *o*. By this means we can multiply the hydraulic pressure set up by the closing of the valve. The hydraulic system is thus so devised that different parts of it fulfil the same functions as corresponding parts of the electrical system. It is well to emphasize, at present, that the air chamber in the hydraulic system is useful only in permitting a defective valve to close without injury to itself. If a valve were constructed that would withstand the resultant shock, there would be greater instantaneous pressure on the piston *m*, and therefore on piston *n*, if the air chamber were omitted. In the same way, if we could construct a breaker mechanism in the electrical system capable of breaking a current instantly without the aid of a condenser, we would get a stronger electrical impulse in the primary and therefore a stronger one in the secondary.

Oscillating Voltage

Fig. 2 shows an oscillogram of what occurs in the primary circuit of an ignition system when the secondary is disconnected. The lower record is that of the primary

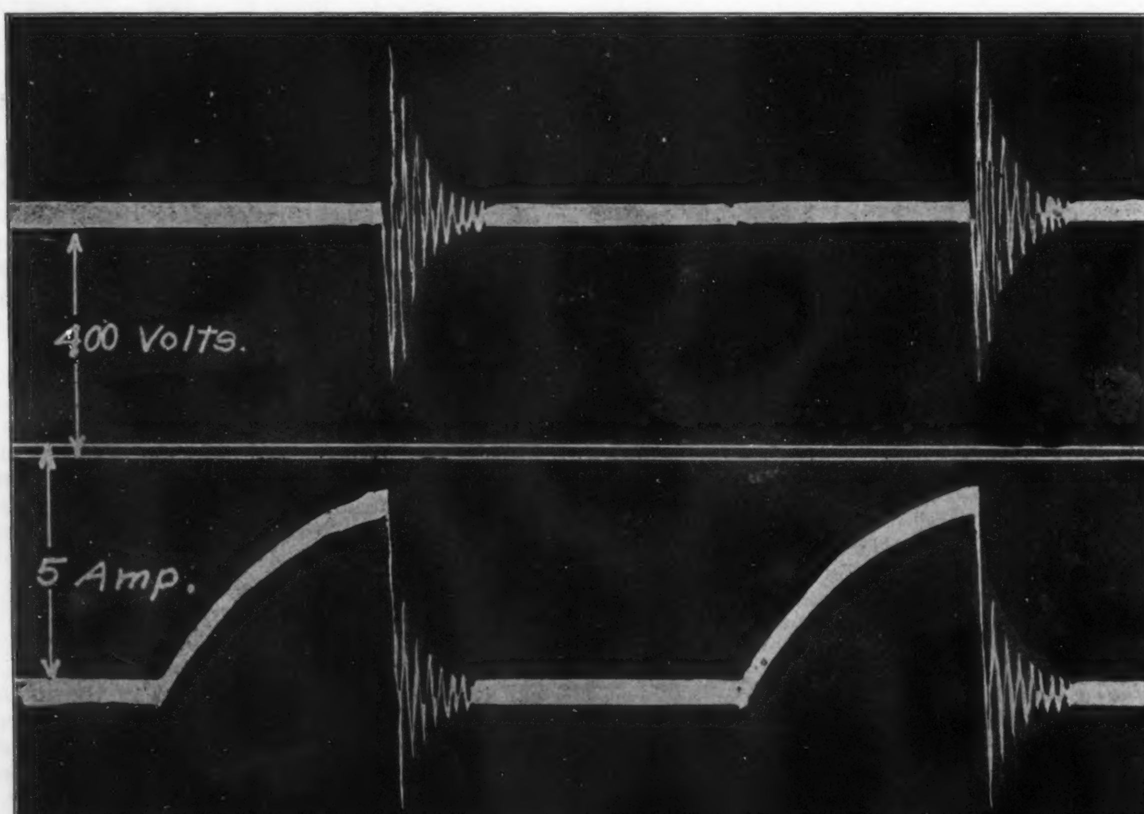

Fig. 2

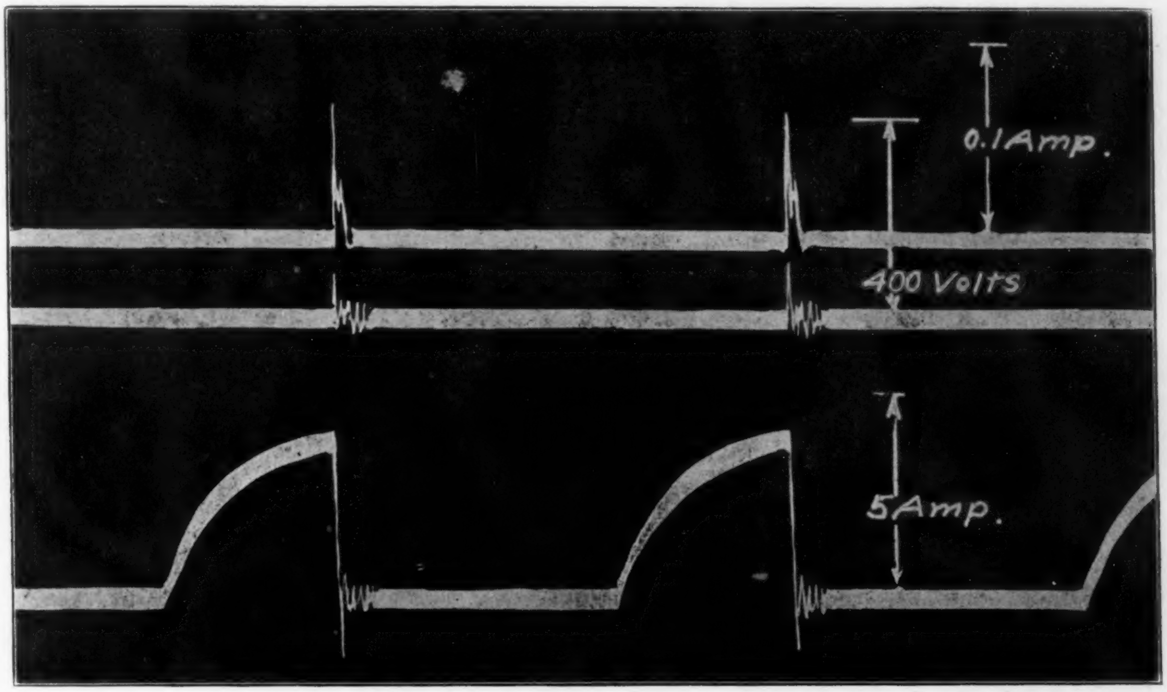

Fig. 3

current. When the circuit is closed, the current increases gradually toward its final value, following a logarithmic curve. The curve was taken with a four-point cam rotating at 1200 r.p.m. The interval, therefore, from the time the circuit is first closed until it is closed again is 1/80 sec. The upper record shows the voltage across the terminals of the condenser, which is practically the same as the voltage across the primary of the coil during the period immediately following the separation of the contacts. When the contacts separate, the current in the coil decreases very rapidly. The decrease of current causes a voltage to be generated in the coil, the direction of this voltage being such that the tendency is to maintain the current in its original direction. This voltage is impressed upon the condenser, which is parallel with the contacts, causing electricity to flow into the condenser. As the amount of electricity in the condenser increases, its voltage opposing the flow increases. We can finally reach a condition where the current has dropped to zero and, neglecting losses, all of the energy formerly in the magnetic circuit of the coil has been transferred to the condenser, the voltage of which has now reached a fairly high value. The condenser now discharges back through the coil, the current flowing in a reverse direction. The oscillogram shows clearly a reverse current after the breaking of the contacts. This current stores up energy in the coil and, as the current starts to die out, the voltage of the coil tends to continue this reverse current, charging the condenser in the reverse direction. The reverse-charge condenser discharges back through the coil, establishing a current in the original direction. On the oscillogram this second current in the original direction is shown at the first peak after the break, with a value approximately one-half the original value of the current at the break. The decrease is due to resistance and iron losses in the electric and magnetic circuits. The upper record shows an oscillating voltage across the condenser first in one direction and then in the other, there being several oscillations before the energy is absorbed.

The most important fact from an ignition standpoint is that the voltage of the first oscillation is highest. As mentioned above, the upper record shows the voltage across the condenser. So far as the operation is concerned, the voltage across the primary coil is identical in value, being placed one-quarter of a cycle away in time. The voltage generated in the secondary, which is wound about the same core as in the primary, follows an exactly similar wave, the voltage being greater in the ratio of the secondary to the primary turns. It is obvious then that if a spark in the secondary circuit is to occur, it must occur by the time the first peak in the voltage wave is reached. If this first peak is not sufficiently great to cause a spark, there will never again be a voltage high enough for a spark. As a matter of fact, in an ordinary system the primary voltage required to produce a spark in the secondary will rarely reach one-half the maximum voltage that is available. The natural period of oscillation between the primary and the condenser for many commercial ignition systems is between 3000 and 5000 complete cycles per sec. The spark must occur in the first quarter cycle and, owing to the shape of the wave, in less than one-half of the time of the first quarter cycle if the voltage actually used does not exceed one-half of the maximum available. If we assume 3000 cycles per sec., taking a lower value, the spark must then occur in 1/24,000 sec. For an engine running 3000 r.p.m., i.e. 50 r.p.s., the engine turns only about two-thirds of a degree from the time the contacts separate until the spark occurs.

The above point is brought up because so much has been said about the lag of the battery spark. The very slight lag already mentioned is due to the necessity of charging a condenser up to the primary voltage at which a spark occurs. The conditions are exactly the same in the high-tension magneto, and there is no more lag in one system than in the other. We are discussing modern battery systems where the spark is controlled by a mechanical breaker which is driven by the engine. In some of the early battery-ignition systems, the circuit was closed by a commutator and the break occurred from the operation of a magnetically operated vibrator. There was an appreciable time-lag with this vibrator which

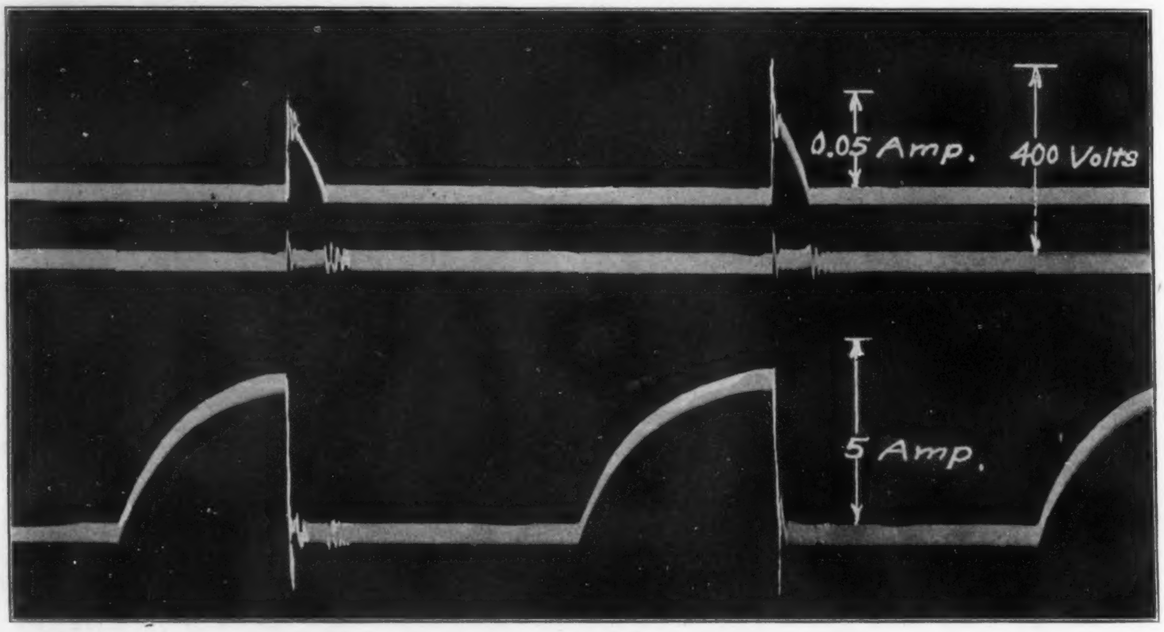

Fig. 4

was constant in time but varied in degree with varying engine speed. Many seem to have the lag of the vibrator system in mind in discussing battery ignition.

Spark-Plug Gaps and Current Values

In Fig. 3 on page 539 the same coil is discharging in air across a ¼-in. spark-gap between sharp nickel points. The primary current looks much as it did before, except that the large oscillation after the break has disappeared. The voltage across the condenser is very different. At the instant of break there is a sharp peak, the voltage dropping back from this value as a result of the establishment of the secondary current across the gap. After this the voltage across the condenser is maintained at a fairly constant value, increasing very slightly throughout the period of duration of the secondary current. The secondary current is shown in the upper record. After the stopping of the secondary current, we see an indication of a very slight oscillation across the condenser terminals, and also in the primary current below. This oscillation occurs because the secondary current stops while the condenser voltage is still above zero, and the small amount of energy left in the condenser sets up an oscillation which is, of course, very feeble as compared to that of Fig. 2 on page 538. We know from other tests which do not concern the present discussion that the maximum value, represented by the first peal of voltage across the condenser, is less than the value existing at the instant the spark is established. The first impulse of voltage lasts for such a very short time that the oscillograph cannot give us a complete record.

Fig. 4 shows the operation of the same coil when discharging across a spark-plug gap set at 0.030 in. under 60 lb. per sq. in. air pressure, this air pressure requiring more voltage than 90 lb. per sq. in. pressure on a mixture under engine conditions. Since much less volt-

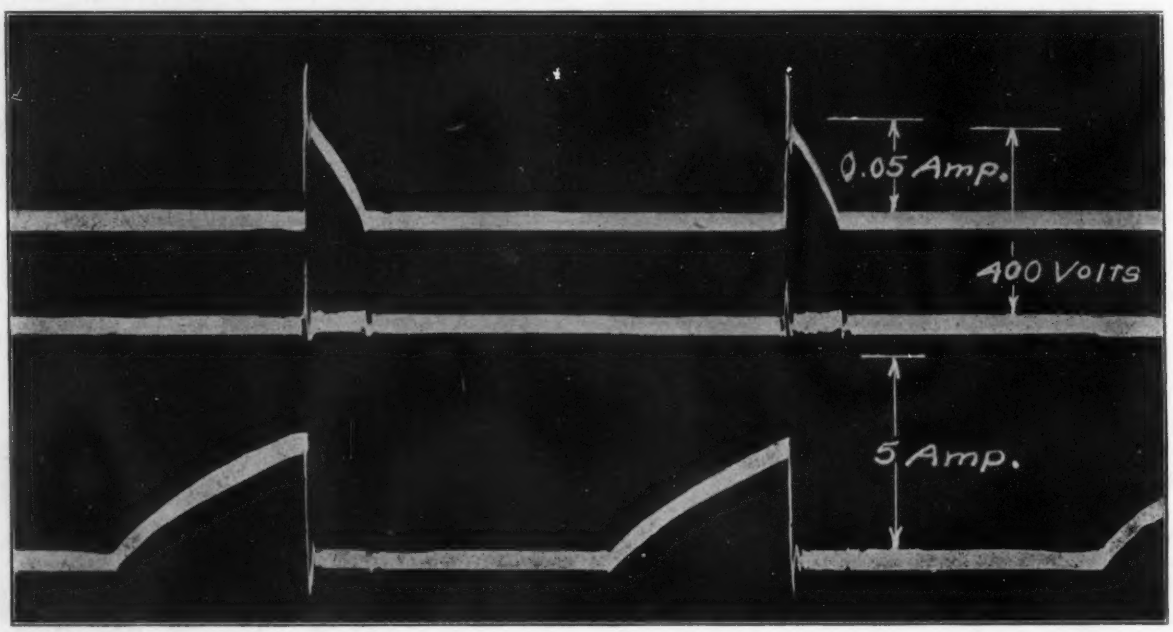

Fig. 5

age was required to maintain a spark across a short gap such as this than across the long one in Fig. 3 on page 539, less energy is dissipated in a unit of time for a given current. As a result, for a given amount of coil energy, the spark lasts much longer. We can see more clearly on this oscillogram the rising voltage across the condenser with the decreasing secondary current, and also the small primary oscillation occurring after the spark ceases.

Fig. 5 illustrates the same conditions as Fig. 4, except that a coil of large inductance and somewhat smaller transformation ratio was used. With a larger inductance the current builds up more slowly. The duration of the spark at the break, for a given current, is longer on account of the larger amount of energy available. Comparing Figs. 3 and 4, the initial value of the secondary current is apparently the same for both cases. This is as it should be. Theoretically, the initial value of a secondary current is the primary current at the break divided by the ratio of transformation, neglecting the very slight current change needed to generate the voltage to cause breakdown.

Fig. 6 shows what occurs when the condenser is disconnected. The upper primary current corresponds to the upper secondary-current record, the condenser being connected in the proper way for this test. When the condenser is disconnected, instead of getting a clean break when the contacts separate, the downward line is thicker and more sloping than usual. The thickness of the line is an optical effect, due to the fact that the beam of light from the oscillograph mirror is much wider in the vertical direction than in the horizontal. The difference in the slope, however, is due to the fact that the current is dying out much more slowly than under normal conditions. As a matter of fact, the energy of the coil is being dissipated at the primary contacts, rather than in the secondary spark-gap. This dissipation of energy of the primary contacts is exactly what we had in the old make-and-break ignition systems with the contacts installed inside the cylinder. From the electrical standpoint this is more efficient than using a transformer but has proved commercially impossible mechanically for high-speed engines.

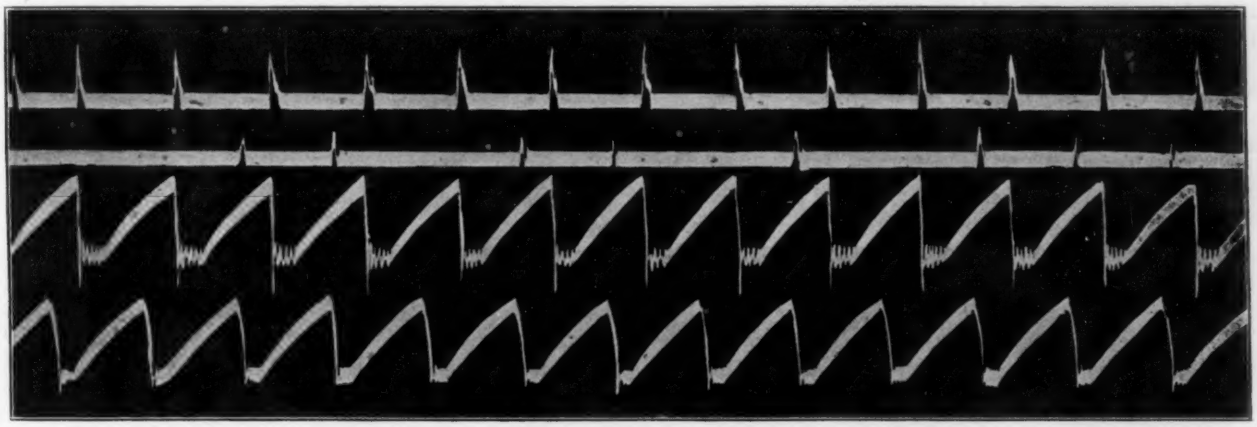

FIG. 6

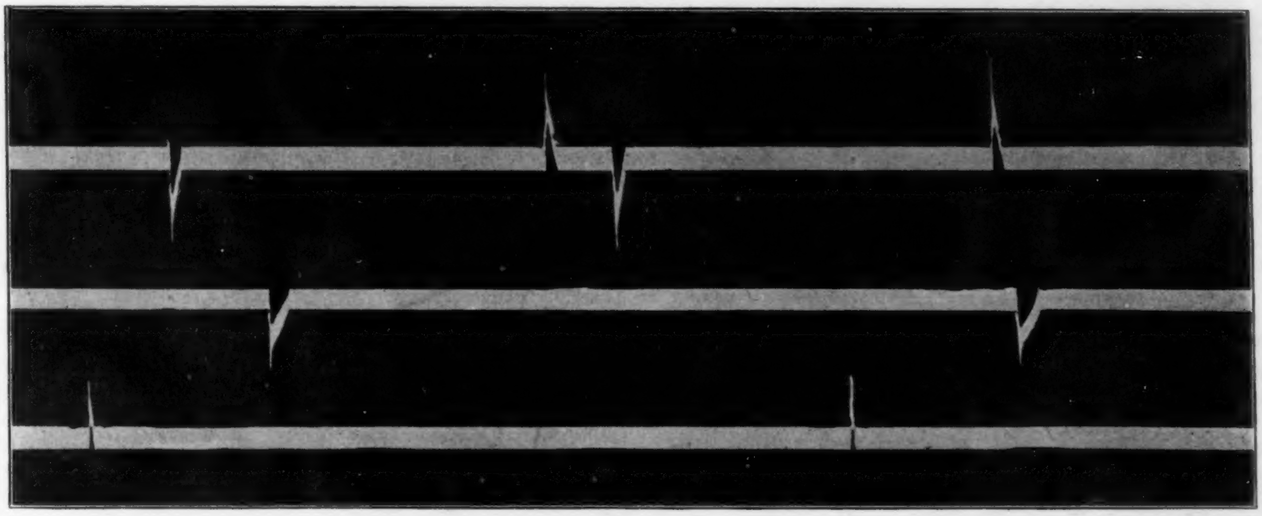

FIG. 7

Fig. 7 shows the spark discharge of a well-known high-grade high-tension magneto at low speeds. The two lower records show a spark at full advance and full retard at 170 r.p.m. of the magneto, corresponding to 114 r.p.m. of a six-cylinder engine. The upper record shows the spark at 200 r.p.m. of the engine. These records are included to show that at moderate speeds the spark from the magneto is identically the same kind of a spark as we obtained from the battery ignition, the discharge wave being triangular, showing a relatively high initial value and falling quickly to zero. This is exactly what would be expected from a knowledge of the circuits in a magneto. From the electrical standpoint the fundamental

difference is that a rotating armature is used for the source of energy instead of the battery. The electromagnetic energy is stored up in the leakage circuit of the magneto armature, and is released by a breaker mechanism with a condenser in parallel, just as has already been outlined. In the case of the high-tension magneto the source of energy, the device for storing energy and the device for transforming energy, are all contained in one element which is the armature with its double winding. There is no essential difference in the operation, so far as fundamentals are concerned, whether the armature rotates in the ordinary machine with the shuttle-type armature or is stationary as in the inductor types.

In the magneto the transforming device is also rotating during the time of discharge, and the high-tension winding with its many turns is capable of acting as a generator. It is a well-known fact that very much less voltage is required to maintain a current than is required to establish it across a gap in air. The oscillograms in Figs. 3, 4 and 5 on pages 539 and 540 have given some indications of the difference. At the higher speeds enough voltage is generated in the secondary winding of the armature to cause a current to flow between the spark-plug electrodes after the initial spark has once broken down the initial higher resistance.

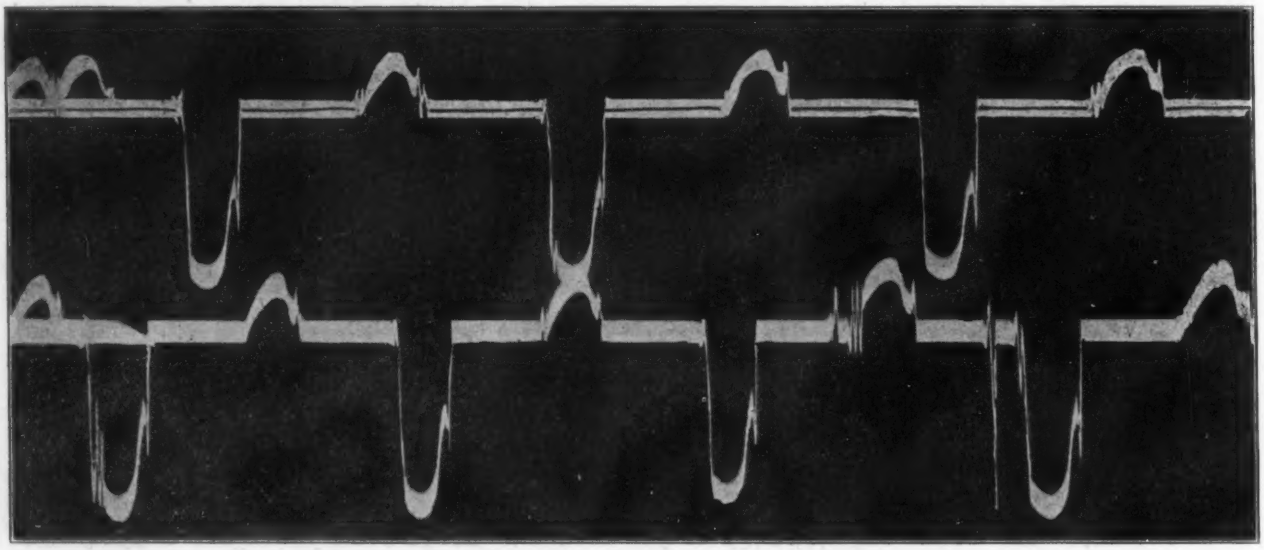

Fig. 8

Magneto Speeds and Spark Polarity

Fig. 8 shows the same magneto as that in Fig. 7 on page 541, being operated at speeds corresponding to 2400 and 2670 r.p.m. of a six-cylinder engine. The record shows an initial triangular discharge such as occurred at the lower speeds and, added to this, a generator current which causes the current increase to a higher value than that due to the initial discharge. At more moderate speeds the sparks of both polarities were identical, but at the high speeds of this particular test it was very noticeable that the sparks of one polarity are very much stronger than those of the other polarity. This record was taken when discharging across a very long gap, ¼ in. in air. The long gap would have a tendency to hold down the generator current to a much greater extent than would the short gap between the spark-plug electrodes. Attention is called to these conditions for the reason that much has been said of the advantage of the flame of the magneto spark, this flame really being due to the prolonged duration of the generator current. The initial value of the magneto current at the high speeds is usually larger than the initial value of the battery current in commercial systems. If the high initial value and high value of the flame current for the records on the upper side of the zero line in Fig. 8 are of any value, there must be a corresponding disadvantage due to the small current and small initial value on the lower side of the zero line. As a matter of fact, the magneto would undoubtedly operate an engine satisfactorily with the sparks of the different polarity differing as much as shown in the oscillograph. In watching these unbalanced sparks at high speed it has been very interesting to see the strong spark shift from one polarity to the other at times. The weakness of the spark of one polarity is due entirely to the excessive current strength of the preceding spark. We see that the current drops abruptly at the end of the spark. This is because the primary contacts of the magneto close again, and the secondary ampere-turns are transferred to the primary circuit as providing the easiest path. This results in a large current in the primary that must be brought to zero before a current can be built up in a reverse direction for the next spark of the opposite polarity. The larger the current, the more difficult this is, with the result that the current in the primary at the break is liable to become very weak if the spark immediately preceding is a very strong one. Since the second spark is weak, there is no current condition to prevent the third spark from being again as strong as the first. Having a magneto discharge across a rotating gap will eliminate the ionizing effect of one spark upon the gas through which the succeeding spark must jump, but will not eliminate the unbalance already discussed. This phenomenon has been observed with practically all makes of magneto employing the shuttle-type armature. I do not wish to imply that these conditions represent a fatal disadvantage in any high-tension magneto. They are brought to attention as an interesting difficulty with which the magneto designer must contend, and to show that the so-called flame of the high-tension magneto is not necessarily a great advantage. Under conditions that can easily occur in the engine, it may cause a weakening of a part of the sparks to a point where their igniting value is less than that

available from ordinary commercial battery systems. As all of the oscillograms have shown, the spark duration of the high-tension magneto may be very much greater than that of the battery system, due to the generator action of the secondary windings at the higher speeds. This flame has been claimed to be of great importance in ignition. A great number of comparative tests have been carried out in the presence of engineers with whom I have been associated, and in no case has any difference been found in the power with battery ignition and with magneto ignition. Furthermore, in no case has it been found necessary to provide any greater advance with the battery ignition than with magneto ignition. Since this is so, it seems obvious that the ignition is accomplished by the very first part of the spark discharge. This is just what we would expect from an analysis of the probable conditions. The spark jumps across the gap between the electrodes through a small volume of the mixture the diameter of which is from 0.015 to 0.030 in., depending upon the gap between the spark-plug electrodes. When this mixture has once ignited, we have flame propagation from this small volume in all directions. Any follow-up flame must pass through burnt gases and, since the heat energy of the spark is very small compared with that of combustion, no effect from the current wave will appear in the power.

Effects on Engine Power

The real answer to the power question can be found in the fact that in the last six or seven years many high-grade cars have changed from magneto to battery ignition. These changes were all made after careful tests by engineers who had a reputation to maintain and who were employed by companies that would sacrifice no fraction of performance to make a small saving in the purchase cost of the equipment. As a matter of fact, in many cases the battery-ignition equipment has been as expensive as the magneto equipment it has displaced. The fact that these changes have been made can be taken as evidence that there is no loss in power in an engine when using battery ignition as compared to magneto ignition.

Figs. 9 and 10 show the results of two comparative tests made on the same engine with battery and with magneto ignition. The magneto ignition was set for 25 deg. of spark-advance as the best position for flight. The battery ignition was tested at 20 deg., giving slightly increased power output up to 1900 r.p.m. and less at higher speeds. When the battery ignition was advanced to 22½ deg., there was a very slight loss of power at the lower speed and the point where the power curves crossed was raised to 2100 r.p.m. If the battery ignition had been advanced further to the same position as that of the magneto, the results undoubtedly would have been identical for the two ignitions. The tests were made by a neutral observer under exactly the same conditions; even the spark-plugs were the same. The tests were made on the same day, less than 2 hr. apart; the barometer readings were the same.

If there were any advantage in magneto ignition, it might be expected to be evidenced in the comparatively large airplane-engine, especially in view of the fact that it is believed by many that the velocity of turbulence in the mixture may be greater than the velocity of flame propagation. If this were really true, an unignited mixture would be drawn past the spark-plug across which the long drawn-out flame is passing, with the result that the time of combustion would be cut down. The tests on the engine given above and other tests on larger engines

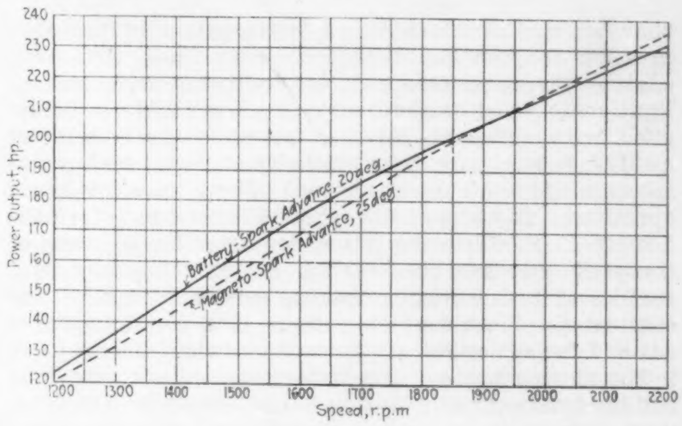

Fig. 9

prove that this does not occur, at least to an extent affecting power. The net results of all of the comparative tests is to prove that all we can do with an ignition system is to ignite the mixture. The mixture must furnish the power.

Battery and Magneto Ignition Compared

The magneto displaced the ordinary battery-ignition systems on the early automobiles because the magnetos were capable of more reliable operation than the types of battery system then available, and because there was at that time no means for keeping batteries charged. For the last six or seven years there has been a very strong tendency in the reverse direction, due principally to the reasons which will now be enumerated. It is possible to get a much stronger spark at very low speeds with battery-ignition systems than can be obtained with commercial magnetos. Since the spark strength depends simply upon the current at the break and the design of the coil, the spark is at all times under the complete control of the designer. Experiments have shown that a strong spark is needed usually in starting and in the lower-speed running conditions, especially when the engine is still cold, rather than at high speeds. The battery ignition can meet this condition much more easily than can the magneto.

There are no limitations upon the range of advance which is possible with battery ignition, as is the case with most designs of magneto. This makes it possible to have a considerable retard available for low speed, idle running and tuning purposes, and yet have the advance necessary to take care of the highest speed. The amount of advance necessary is governed principally by the spark-plug location and the dimension of the combustion-

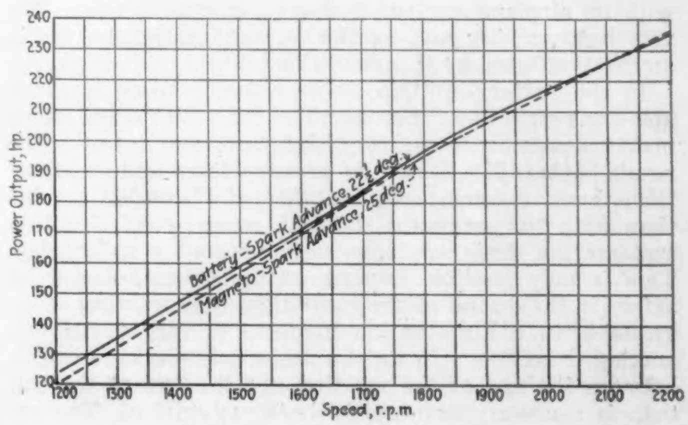

Fig. 10

chamber, and is affected to a lesser extent by the compression and the quality of mixture. There are many engines giving satisfactory service today with battery ignition to which the ordinary magneto could not be applied with sufficient advance for high speeds without making it necessary to crank with a very considerable advance and with unsatisfactory effects upon low-speed operation. In some of his recent discussions before the Society C. F. Kettering has called attention to some of the work that has been carried out in connection with fuel knock and indicated that we can hope to have this eliminated. If this is done, there is a possibility of a demand for somewhat greater advance than is now used.

The moving parts of the battery system are very light and the total amount of torque variation required to drive them is exceedingly small in quantity whatever the variation in percentage may be. As a result of this it is very easy to apply the automatic advance to the battery type of ignition. This has not yet been done, at least on a very large scale, on magnetos as applied to passenger cars. It has been found possible to attach automatic advance to engines in such a satisfactory way that the engine performance is better not only during ordinary driving but during acceleration, without touching the spark control, than can be obtained by a skilled driver manipulating the spark with a system not provided with automatic advance. The satisfaction that this performance has given the user has undoubtedly been largely effective in the reintroduction of battery ignition.

Attention has been called to the lighter moving parts of the battery-ignition system. This has proved particularly advantageous for installations on very high-duty engines where the materials used are highly stressed; for example, on airplane engines. The crankshafts of these engines are stressed to a much greater degree than are the crankshafts of ordinary engines. The result is that considerable torsional vibration exists at the end of the crankshaft opposite the propeller, which serves as a flywheel. In geared-down engines the crankshaft can oscillate through an angle corresponding to the gear clearances without being retarded by any flywheel effect except its own inertia. We have made tests on a standard Liberty 12-cylinder engine which showed that the vertical shaft driving the generator oscillates 6½ deg. under full load, on either side of the position during the rotation. As there is some gear clearance between this shaft and the crankshaft it does not follow that the crankshaft oscillates about 40 deg. at this end, but there is an appreciable oscillation. The magnetos on airplane engines are usually mounted opposite the propeller, under the point where this torsional vibration is greatest. It is very probable that the large amount of magneto trouble met with on airplane engines is due to this oscillation. The very light moving parts of the battery ignition are not in any way affected by this condition.

In the battery-ignition systems ample space is available for proper insulation at all of the vital points. This makes it possible to use very high factors of safety. The result is that, in a system of proper design and construction, there is much less possibility of insulation trouble than with the magneto. In fact, most battery-ignition systems are designed to be used without a safety-gap. This is only possible because of the greater factor of safety in the design of the insulation. The winding space available in a high-tension magneto is very restricted, making it necessary to use a much smaller leakage length between the end of the winding and the end of the coil than is necessary or usual in battery ignition. The reduced insulation strength makes a safety-gap necessary, which is undesirable from the operation standpoint. Without a safety-gap it is possible for an ignition system to operate even if the spark-plug electrodes are greater than normal, due to warping of the electrodes. The voltage required to jump the gap when oil has just been splashed on the spark-plugs is greater than normal. The film of oil on the spark-plug electrodes is a very good insulator and a spark-plug in this condition requires more voltage to jump the gap than when the plug is clean.

Much has been said about the advantage of the follow-up flame in handling oily engines, the theory evidently being that this flame or arc of the magneto will actually burn the carbon deposit from the spark-plug insulator. Some time ago we ran a careful comparative test between battery and magneto ignition to determine, if possible, if there is any such advantage. We put an extra gallon of oil in the crankcase of a small engine and ran 50 hr. at 1200 r.p.m. at light load so there would be plenty of suction to lift the oil above the pistons. The operation was entirely satisfactory throughout the run with battery ignition. When we attempted to repeat the test under otherwise identical conditions, but using a magneto giving a strong flame at this speed, ignition failed in about 30 hr. due to the formation of a carbon bridge between the electrodes of one of the spark-plugs. I feel convinced that the flame of the combustion of the mixture, which of course has very much more heat than any ignition device could possibly supply, is the flame which keeps the spark-plugs clean. The essential thing in an oily engine is to keep the engine hitting. In case missing occurs the spark-plugs begin to foul and the oil deposits have a chance to bake in place. The essential thing is to have a secondary-current wave with a very steep wave front and a sufficiently high initial flow of the current. The wave front of the battery system is equally as good as that of the magneto, and the initial value of the current is under the control of the designer and can be made whatever is necessary. The higher voltage available as the result of the absence of the safety-gap gives an advantage in favor of the battery ignition. The follow-up flame is a disadvantage in high-speed engines in that it eats away the spark-plug electrodes, requiring frequent adjustment of the spark-plug gap and more frequently renewal of the spark-plugs. Inasmuch as the flame does not assist ignition, its absence is an advantage in favor of battery ignition. I have been told by a man who has driven an English cyclecar that when the average engine speed is high, he has found it necessary to readjust the spark-plug gaps about every 800 miles, on account of the eating away of the electrodes, and to renew the spark-plugs about every 4000 miles.

A very important advantage of battery ignition is the ability to use tungsten contacts. These seem to require a fairly high circuit voltage to take care of the contact conditions. This makes their application to magnetos difficult when good low-speed and starting characteristics are essential, although the present commercial situation is compelling many magneto manufacturers to study the situation very carefully. The tungsten contact is much less subject to pitting than the platinum-iridium contact; furthermore, it has a very much longer life and requires less frequent adjustment than the platinum alloy.

A well-designed battery-ignition system is much less sensitive to breaker adjustment than the ordinary magneto. Most magnetos drive the cam at engine or at 1½ engine speed, making necessary very gradual rises of the cam to prevent injurious effects on the breaker mechanism at high speeds. The more gradual rise of the cam increases the effect upon the timing of relatively slight

changes in adjustment. Since it is necessary for the magneto to have the contacts open on the proper part of the current wave, the contact adjustment must be maintained much more closely to the ideal setting than is necessary with the battery type of ignition.

A very important advantage in battery-type ignition is the ease of inspection of the various elements due to their separation, making it possible in case of any doubt as to performance to determine just exactly what the questionable element is and to repair or replace this if necessary. Under conditions where it is vitally important to be absolutely certain that the ignition system will function satisfactorily, where failure would be disastrous, as during a speed contest of transatlantic flight, it is possible to make sure that every element is in a satisfactory condition. This has a further great advantage to the user of the ordinary automobile installation in that the cost of service is greatly decreased. Reliability and ease of maintenance are the most vital factors in the success of any system and the record of the high-grade battery-ignition systems which have appeared in the last few years compares more than favorably with the competing equipment.

We do not claim any increase in power for the battery system as compared to the magneto system since, as already stated, all the ignition can do is to ignite. It is, however, usually easier to install a battery system in such a way as to insure that the maximum power will be maintained. We have a record of satisfactory performances of battery ignition during speed contests, altitude and transatlantic flights, which proves conclusively that battery ignition will function and give satisfactory results under the most severe conditions of service. The position of battery ignition is exceedingly favorable when judged by the acid test of experience.

The Discussion

E. L. Clark:—Is there any advantage in the intensifiers sometimes used?

J. H. Hunt:—There is an advantage under certain conditions. I believe it is better to remove special conditions than to use a special type of ignition. I have seen some tests in which, with a coil on the spark-plug, a very high frequency was used; the frequency was so high that one could permit the spark to jump through one's fingers without feeling it. There was no difference in the engine performance under normal conditions. This ignition was being tried out on an engine in which there was a tendency for oil to get on the spark-plugs. An oily plug or one with a cracked porcelain would fire when ordinary ignition would fail.

There is a certain advantage in putting an extra gap at the spark-plug. It seems to act as a kind of dam to hold back the current surge until it is strong enough to arc across. The benefit comes from the change of wave-front at the plug. The disadvantage is, however, that the gap wastes from 20 to 50 per cent of the total energy available for the spark. To pay for the improvement one may get when the engine is running, the result is an engine that is hard to start. Since the only advantage of such a device is under abnormal conditions, it seems best to eliminate these conditions.

E. T. Birdsall:—Will Mr. Hunt explain the Philbrin system? It seems to have some advantages on racing cars.

Mr. Clark:—It consists of two systems, so that a change can be made from one to the other. One is the ordinary system used previously.

Mr. Hunt:—It is hardly fair for me to attempt to discuss the Philbrin system. I have seen it in operation and have never observed any sparks that I would wish to put my fingers on. It includes a vibrator giving a series of sparks. We formerly felt that this was an advantage, but gradually eliminated this type of construction. We understood that it was not of enough advantage. With a cold engine a series of sparks might be of some advantage. I believe the Franklin company has installed a device to secure this result on its car.

Fred W. Andrew:—Mr. Hunt stated that no magneto on the market has an automatic advance. The Holmes car is equipped with an automatic-advance magneto that has been on the market nearly six years. Regarding the trouble with the airplane drive, we used an 800 Splitdorf magneto. The real trouble was that it was connected too rigidly, and had nothing to do with the magneto. This was corrected by installing a modern flexible drive. The Rolls-Royce aeronautic engine had four magnetos but only two were necessary. Concerning the curves shown of the six-cylinder engine Mr. Hunt referred to, my opinion is that the magneto was not adjusted. To make a magneto suitable for high-speed work, the pole-shoe gap must be different.

Mr. Hunt:—Mr. Andrew is right. It is possible to obviate some of the magneto limitations mentioned. In testing magnetos I have observed that when a spark of one polarity was stronger than that of the other, frequently the strong spark would shift from one polarity to the other while the magneto was running. I did not bring out this point of varying spark strength of different polarities to indicate that the magneto failed. The point is that if the weak spark that occurs at times of one polarity is enough, there can be no particular advantage in the strong spark of the other polarity.

Roger Chauveau:—Concerning the unbalance of the magneto as shown, such a condition is apt to occur when a magneto is run in connection with the open spark-gap. It is still worse if the spark-gap is enclosed, in an air-pressure of 40 to 60 lb. per sq. in., as stationary air cuts down the resistance of the spark-gap. If that takes place in one, it will cause the unbalancing. That condition cannot exist in an engine, because a fresh charge is introduced at each explosion and the gas between the electrodes of the spark-plug is changing for each spark. That prevents unbalancing from taking place. To make a correct test, it should be made with a magneto on an engine that is running. I have often produced the same effect. We cannot overcome the spark-gap trouble in open air.

Mr. Hunt:—I have tried to eliminate the effect by using a rotating gap. The tendency is reduced but not eliminated. Have you taken any oscillograms with a magneto connected with the engine? I raise this question because when the gas between the points is burning after ignition, it is in an ionized state and I cannot imagine a better gap for the follow-up current to build up in than exists in the engine.

Mr. Andrew:—I think weak sparks in a magneto are unnecessary. A magneto should not be shipped out in that condition. It is easy to correct when one knows how. Will Mr. Hunt say something about the amount of spark heat required to fire a gas engine? Does he think there are cases when a battery should be used and when a magneto should be used?

Mr. Hunt:—I think there is room for both devices. It has been demonstrated that battery ignition is excellently adapted to a wide range of service. If, however, the battery is not going to be taken care of or it cannot be mounted in a proper manner, naturally battery ignition will not be entirely satisfactory. I suspect that such con-

ditions exist on tractors. Many tractors are left standing for months without giving the battery attention. It is likely that magnetos will be used on tractors for some time.

We were somewhat surprised when we were asked to undertake the ignition for the Liberty engine. We had assumed that the magneto would be considered preferable by the airplane engine designers. However, when we learned exactly what the requirements were, we found that there were many advantages in battery ignition. It was possible to construct a battery installation that was lighter than that of the magneto then available, and skilled mechanics and trained men obviated questions of battery maintenance. This is not necessarily true of all airplane engines for every condition of service. The report of the French Technical Committee, which was made after official government tests, was favorable to battery ignition for airplane engines of large power.

In regard to the energy required I have no figures available, but I am sure that an engine can be run and maximum power obtained with less than 1/100 of a joule. An exceedingly small amount of energy is required after the engine is warmed up and running. It is preferable to have more energy available when starting, possibly as much as 5/100 of a joule which, of course, is possible with battery ignition.

MR. ANDREW:—We are working along those lines. I am talking of commercial conditions. We are too apt to consider a gas engine in perfect condition. Ignition that will operate perfectly well normally may be useless at extreme temperatures such as occur in truck engines on hot days or when starting cold in winter. There are certain battery and magneto-ignition systems that will not operate properly under these conditions. For that reason I say that we must not judge ignition by laboratory tests. Pistons frequently fit poorly, the valves do not seat and the carbureter is adjusted badly. All that must be taken into consideration. Mr. Hunt has said that the spark heat can be changed. It can, but at greater cost. If there is any indicated place for battery ignition, it is on the low-priced cars.

MR. HUNT:—Many cars having battery ignition are hardly in the low-priced class.

H. L. HORNING:—What experience has Mr. Hunt had with battery ignition having direct cam action, or a kick-off similar to that in the Atwater-Kent system?

MR. HUNT:—I take it Mr. Horning refers to the interval of time involved by the contacts being pressed together by cam action, as compared with the type in which a trigger is released? There is no doubt a lag in the latter. We have had two different types of breaker mechanism. In the earlier type the cam forced the contacts together and a spring opened them. There was a lag. We have every reason to believe there is no lag in our present type of ignition.

The duration of contact made by the trigger type has a bearing on the lag of the spark after the cam gets to the position where the spark occurs. To give the same joule-energy consumption per spark at low speeds as at high, the dwell at low speeds has had to be limited and a fast coil used. It was desirable to put on an automatic advance to take care of the time after the cam got to the point of releasing the hammer.

A MEMBER:—The lag is variable in degree with the speed of the engine; constant in time, variable in degree. In other words, the actual period varies the wrong way in comparison with the engine speed. That is true with all of those mechanical breaking mechanisms. The non-positive contact breaker is an accepted design, is it not?

MR. HUNT:—I do not wish to commit myself in regard to that.

C. E. WILSON:—Was a three-point gap used in testing the ignition system under discussion? If a two-point gap is used, it is difficult to get consistent results. We have eliminated our testing troubles by using a three-point gap.

With reference to the heat of the spark, a number of tests have been made in the Remy laboratories to determine what value is really required and, while we have not reached a final conclusion, we have found that the heat of the spark is of importance only in cold-weather starting. With the hot spark we found the time of starting was shortened materially. The figure of 50 millijoules mentioned, if obtained at a very low speed, should give very satisfactory results. We have been paying special attention to several cars that have ignition with only 25 millijoules and apparently there has been no difficulty in starting.

My personal opinion regarding battery and magneto-ignition systems is that we really get the same kind of effective spark; that is, during the first fraction of a thousandth of a second, we get the same kind of a spark from each. The problem then becomes one of working out the best commercial way to supply energy to a high-tension coil, whether by putting that on an armature in a magneto, by generating the energy in the magneto, or by using a battery having the ordinary breaker mechanism. I would not recommend installing a generator, a battery, and the ordinary type of battery ignition on passenger cars, if it were not that the battery is required also for the purpose of starting and lighting.

A MEMBER:—What is the effect of having too much condenser capacity? Is there any advantage in having larger condenser capacity?

MR. HUNT:—The condenser determines the voltage of the oscillation and the frequency. If too much condenser is put on, the period of oscillation is slowed down. This is an advantage in eliminating a contact spark but, if the peak is not high enough, the effect is unsatisfactory.

We are able to use a type of contact with battery ignition that has not been used in very great quantities on magnetos. This is said to be satisfactory. The battery-ignition system was the first to use the tungsten contact, and tungsten is a material of which we have a large supply. The difficulty on the magneto seems to be a film which the current cannot cross without a certain minimum voltage. If there is such a film, there will be trouble in starting, although tungsten has been developed that will work better and perhaps eliminate this disadvantage.

MR. ANDREW:—I am familiar with both sides of this subject of contacts. Tungsten is a base metal volatile at 300 deg. cent. (572 deg. fahr.). It can be volatilized with a match. The oxides come off in two forms. One is a bioxide, a gray powder that is a partial conductor of electricity. As soon as we get a trioxide, this is almost a non-conductor. Those who have used battery ignition in the past have had to clean out the space between the contacts. Regarding the so-called improved tungsten, it is on test; we have analyzed it and it appears to be more than 99 per cent tungsten. The chemists do not seem able to find out what composes the other 1 per cent. It seems to work better than straight tungsten. Several magneto companies are using contact points of this kind successfully. On the higher-grade magnetos we are still using 20 per cent platinum-iridium.

MR. HUNT:—The reason we used tungsten at first was because we found that we were not getting the life we

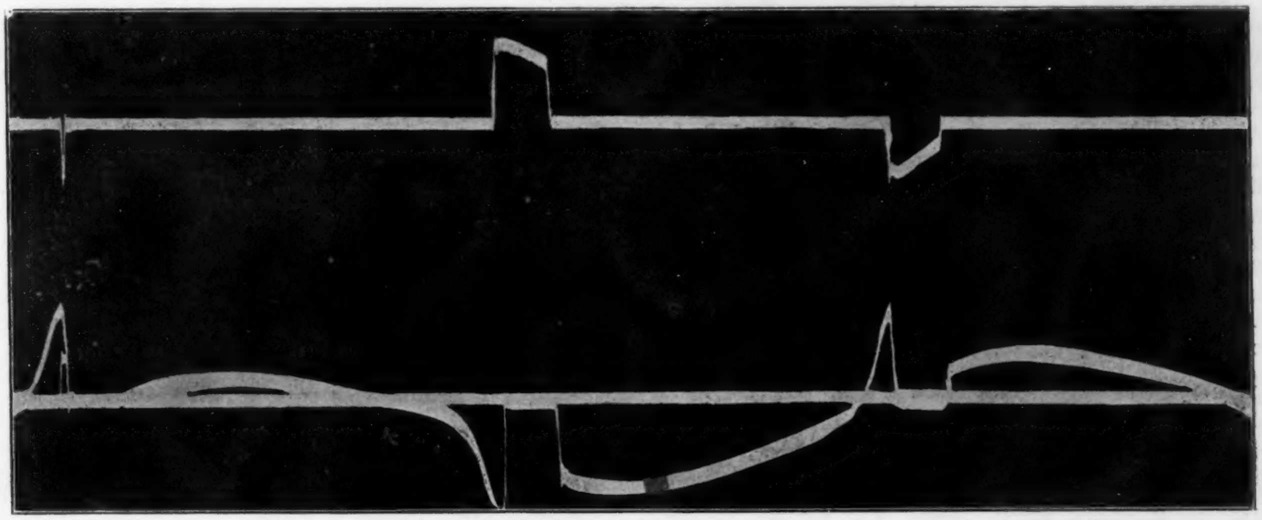

FIG. 11

wanted with the platinum contacts. Due to the development of methods of production and to competition, it is possible today to get tungsten cheaper; but at the time we made the change we paid the same for each and put on the tungsten contacts because they were better.

A MEMBER:—It has been made apparent that the battery-ignition system has advantages in the multi-cylinder engine. Has it the same advantages in a good four-cylinder engine?

MR. HUNT:—The advantages that I claim had to do with the ease of application to the multi-cylinder engine and the saving in weight. They would not apply to the same extent to the four-cylinder engine, because the saving in weight in pounds is not so great. The saving in weight in percentage is about the same. That does not mean that it would not be possible to put a four-cylinder engine system on an airplane, and I would not concede any advantage to the magneto on the four-cylinder engine so far as performance is concerned. Many companies that used magneto ignition changed to battery ignition.

With reference to what causes the weakening of the magneto sparks of one polarity, we have made a test of a standard magneto. Fig. 11 shows the oscillation of a primary and secondary current of this magneto when discharging across an ordinary spark-plug gap at 900 r.p.m. of the engine. The spark-plug was under 90 lb. per sq. in. air pressure. There is already at this speed an indication of a considerable difference in spark strength. Fig. 12 shows the same magneto running at 1600 r.p.m. The sparks of one polarity are very weak and some of them are practically suppressed, while the sparks of the other polarity are very strong. The difference in the spark strength as shown by the oscillogram is obviously due to the difference in the primary current at the instant of break. For the strong spark we see a very large current reestablished in the primary at the closing of the breaker contacts, and this current must be reversed before a current can be established for the spark of the other polarity. After a very weak spark, the primary current in the same direction as the spark is very small. This particular magneto was one which was giving very satisfactory performance on a tractor, and doubtless the makers did not consider it necessary to take steps to prevent the appearance of this phenomenon at speeds that are very usual in motor-car work. The phenomenon is, however, identical with that which tends to appear at very high speeds with magnetos having the same arrangement of electric and magnetic circuits.

In the discussion of a paper entitled Advantages of Magneto Ignition by A. D. T. Libby some reference[3] was made to records which have been made with magneto-equipped engines. Mr. Libby did not give all of the records which were available at the time of his paper and others have been made since which seem pertinent to the present discussion.

The NC-4 machine which completed the first transatlantic flight was equipped with the standard battery igni-

[3]See THE JOURNAL for September, 1920, p. 287.

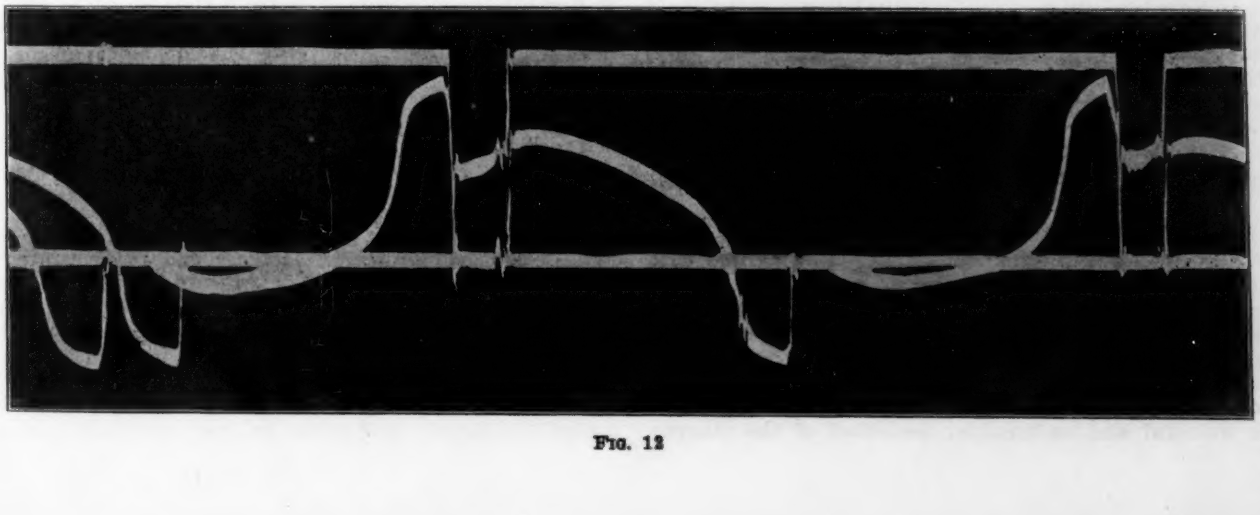

FIG. 12

tion used on the Liberty engine. Major Schroeder made his altitude record in an airplane equipped with a standard battery-type ignition. This altitude record has not yet been surpassed and was 33,000 ft., according to the Bureau of Standards' calibration of Major Schroeder's instruments. In April, 1920, Murphy took the world's record for a 300-cu. in. engine for distances up to 5 miles at Daytona Beach, making a speed of 122.78 m.p.h. for the ½ mile and 120.69 m.p.h. for the 5 miles. Later in the same month Milton broke all straightaway records for 5 miles with a 600-cu. in. engined car, making 155.57 m.p.h. for the ½ mile and 149.95 m.p.h. for the 5 miles.

Cars equipped with battery ignition made excellent speedway records during the summer of 1920. At Indianapolis, seven of the first 10 cars were equipped with battery ignition, including the winner. Garfield Wood won the Harmsworth trophy with a machine equipped with Liberty engines having battery ignition. The 24-hr. speedway record was won by a car equipped with battery ignition and so was the transcontinental record.

The ignition performance implied in the above results obtained with engines equipped with battery ignition should answer any question as to the ability of this type of ignition to meet the most exacting and varied requirements. The real test is of course in the service attained by the user.

FORMS OF ATTACK IN COASTAL WAR

WHAT will be the most popular form of attack in the early stages of a coastal war of the future? Navies still have very fast battle cruisers, plane-carrying craft, submarines, battleships with guns that can fire about 25 miles, large seaplanes and great fleets of destroyers, submarine chasers, etc., that can cross the ocean. They have also airships that can be folded up into bundles smaller than the fuselage of an airplane, and can be inflated upon arrival at a destination and can be supplied and repaired on the deck of a steamer or battleship, or submarine for that matter. In addition we shall see an accompanying fleet of rigid and semi-rigid airships. Helium producing gas wells are common now and the lighter-than-air craft of "to-morrow" is not a traveling charge of explosive. This non-burning gas will probably float a very large majority of the airships which will be built in the future.

It will be necessary to have near every important harbor an air-service establishment with various types of aircraft kept ready for call at all times. There should be reconnaissance planes, chasse planes, day bombers, airships and seaplanes. A properly equipped station should be able to patrol the coast 100 miles each way and to send out craft at least 200 miles to sea. This service in good weather will eliminate surprise even by submarine cruisers. In addition to airplanes and airships there should be local companies to operate captive balloons and what were known as barrage balloons. The captive balloon is very reliable. Observers in it can command vast stretches of water. The captive balloons can control not only the fire of minor-caliber guns but be used to patrol for friendly and hostile mines. They were used for these, while being towed by tugs, in the harbors of the British Channel. They were of value also in hunting down submarines in the harbors and shore waters before the small airship became efficient.

Barrage balloons were used at night to suspend wire entanglements over important objectives. They were so subject to attack by airplane that it was impossible to maintain them in the daytime. Essen was protected by barrage balloons long before the Allies used them in London and Paris. Wires have a great moral effect at night. They did not capture many planes during the war and were as hard on their friends as on their enemies, but nevertheless they will be used to protect coast defenses against low bombing and reconnaissance planes.

An airship can raise and lower itself without the use of its engines. So for spying out a fleet that is using a fog or smoke to hide in, it is very efficient. It can stand by for hours, and perform better at night than in the daytime due to the constant temperature of the air. The airship will be excellent for patrolling friendly mine fields and for destroying hostile ones. Airships and airplanes can supply in part the detached pickets of a coast guard. They will undoubtedly help to reduce the size of coast guards on land.—Col. James Prentice in *Journal U. S. Artillery*.

THE ARMY

THE Army in its truest expression is at least in some of its aspects the highest possible development of a democratic society. It represents law, obedience to law, discipline by the observance of law, complete coordination of function and the very highest efficiency in action of any group that we have These are the qualities which make for success in all societies. If a number of us were cast upon Robinson Crusoe's Island and there was no government there of any sort, and we were undertaking to organize a government of our own, we should try to get into it at the very outset those qualities which I have mentioned, because our experience as civilized men has taught us how essential, how basal they are to any efficiency in governmental organization. The Army has them all. It also has certain defects inherent in the system. Everything has the defects of its quality, and the tendency of such an aggregation of qualities in a society is to make it inelastic, to make it conservative beyond measure, to make it resent change, to make it slow to grow. But these qualities themselves, quite apart from their defects, which have just been mentioned, are fundamental and basic in social organizations, irrespective of their character and location.—Secretary of War Baker.

ANALYSIS OF WING TRUSS STRESSES

REPORT No. 92 which was recently issued by the National Advisory Committee for Aeronautics is concerned with the analysis of the effect of redundancies and particularly of the external drag and stagger wires. The stresses in a typical training machine have been worked out for several conditions of flight, the method of least work having been applied, as an illustrative case. The chief conclusions reached are that the use of more than one external drag wire on each side is wasteful and undesirable, the effect of the stagger wires in speed diving is important and serves to reduce greatly the load in the lift trusses and the advantages in reduction and uniformity of stresses to be gained from the tensiometer in practical rigging are great enough to justify the general introduction of that instrument. In particular the stress wires are usually set up much too tightly.

A copy of this report can be obtained upon request from the National Advisory Committee for Aeronautics, Washington.

Automotive Radiators

By KARL F. WALKER[1]

Illustrated with PHOTOGRAPHS AND CHARTS

THE essential elements of an automatic cooling system are known to all engineers, but the importance and correct functioning of the various units of such a system are more or less vague to many. During the war the Bureau of Standards obtained considerable information on aeronautic radiators, but only

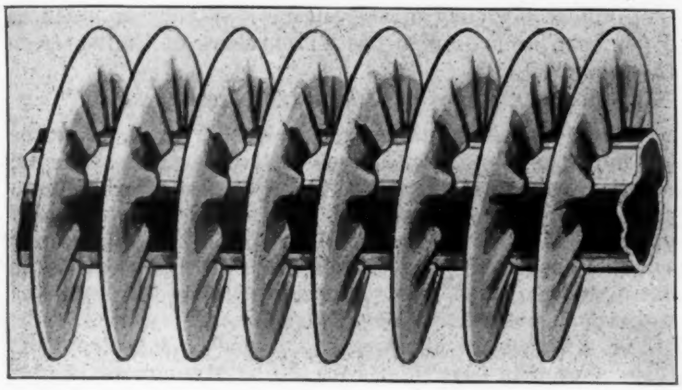

FIG. 1—HELICAL-FIN TYPE OF RADIATOR CORE

a relatively small amount of information is obtainable on cooling systems for various other commercial uses. When the spark ignites the gasoline vapor in the cylinder of an internal-combustion engine, the temperature may rise to about 2800 deg. fahr. and, in another moment, at the end of the intake stroke, the temperature may be only 300 deg. fahr. The mean temperature of the cycle will range from about 900 to 1000 deg. fahr. The effect of these temperatures on cast iron or steel, expansion, preignition, lubrication and the like, necessitates a means of cooling for which water has been found most satisfactory.

For such a cooling system the essential elements are a radiator, cooling fan, water-jackets and a means of water circulation. The factors controlling the heat flow to the water-jackets are the size and shape of the combustion-chamber, the thickness of the cylinder walls, the mean effective pressure of the engine, its cycle, speed and thermal efficiency. Proper circulation through the water-jackets in a pump circulating system is more important than the quantity of water contained therein, since lack of circulation in any one part of the jacket will cause overheating.

RADIATOR CORE CONSTRUCTION

After due consideration is given the water-jacket design, the next important unit is the radiator. The radiator is a misnamed unit. If the heat dissipated by it were largely due to radiation, the radiator core should be painted with lamp black to increase heat dissipation. Most of the heat dissipated by a radiator is by convection.

Radiators can be divided into two classes, dependent upon their direct or indirect cooling areas. The first class covers cores in which practically 100 per cent of the cooling surface has flowing water on one side of the metal and air on the other. The second class may have stagnant water on one side of the metal and air on the other or, it may have fins connected to the direct cooling surface with air on both sides of each fin. The amount of direct and indirect cooling surface varies greatly in different types of radiator. Sometimes as little as 13 per cent of the total cooling surface is direct cooling surface and again it is as high as 100 per cent. Usually direct-cooling radiators have a straight cooling surface from front to back of the core, thus allowing a larger quantity of air to pass through than on similar types of radiator having indirect cooling surfaces. The latter generally contain perforations or some other means for cutting up the air. As heat dissipation is in direct proportion to the velocity of air passing through the radiator, it would appear that direct-cooling radiators would be the most efficient. This is not necessarily true, however, as the perforations in the indirect-cooling core cause increased turbulence of the air, which in turn increases heat dissipation. Too much turbulence may be overbalanced by the reduction in air flow. The proper amount of turbulence of the air is governed by the use to which the engine is put. Indirect cooling surface should be made of metal the thermal conductivity of which is high, and should have a good thermal contact with the direct cooling surface. The value of indirect-cooling surface is limited, since the farther it is from the water channel the less efficient the indirect-cooling area becomes.

There are numerous types of radiator core on the market today, which vary in design, appearance and performance. There is the fin-and-tube type, in which the water runs through copper tubing, usually wound spirally with metal fins as in Fig. 1, or provided with horizontal fins as in Fig. 2. There are various types of ribbon core through which the water flows in a narrow water channel formed between two ribbons which are made of metal usually about 0.005 in. thick. An example of this form of construction is shown in Fig. 3 on page 550. A single-tube type also is made, in which case the tubes are placed parallel to the air flow, the water flowing around the outside diameter of the tubes. (See Fig. 4 on page 550.)

The width of the water channels varies in different

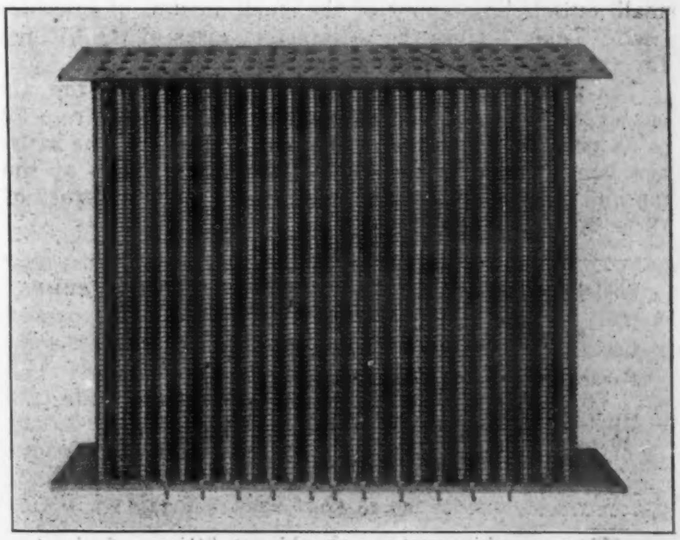

FIG. 2—A FIN AND TUBE TYPE OF RADIATOR WITH HORIZONTAL FINS

[1]M. S. A. E.—Chief engineer, Fedders Mfg. Co., Inc., Buffalo.

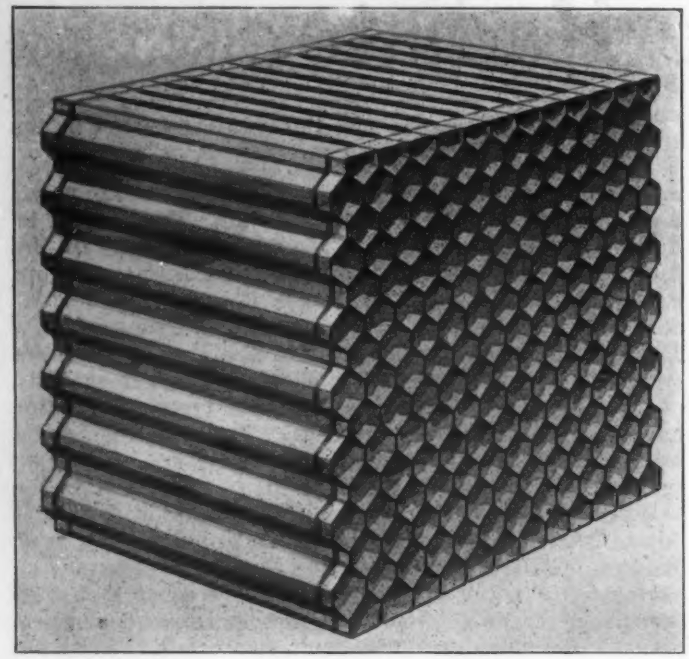

FIG. 3—A RADIATOR CORE OF THE RIBBON TYPE

makes of core of the ribbon and single-tube type illustrated in Figs. 3 and 4, from 0.0280 to 0.0925 in., the average width of some 30 styles being 0.0666 in. The narrower the water passages are, the more turbulent the water flow will be and the more heat the radiator will dissipate. If the channel is too narrow, however, the water circulation through the core will be reduced until the heat dissipation actually decreases. Narrow water passages soon become clogged with sediment that accumulates in the system, and the water circulation is either greatly reduced or stopped. In such cases the water will back up in the top tank and run out of the overflow, due to the fact that the radiator will not be able to handle the amount which the pump is discharging.

Another important factor in radiator design is the size of the inlet and outlet fittings. In many cases these are made too small, resulting in low circulation through the radiator. Poor circulation is not always the fault of the core, but may be due to the small fittings which are specified by the automobile manufacturer. It is impossible to pass a large volume of water through radiators with small outlets on account of the small amount of pressure head. Table 1 gives the satisfactory sizes of the fittings for engines of different horsepower.

The percentage of free area through which the air passes varies on the common types of radiator from 52 to 88 per cent of the frontal area of the core, the average being about 72 per cent. The water tanks at the top and bottom of the core are usually made of brass of 18 or 20 B. & S. gage.

TABLE 1—SIZE OF INLET AND OUTLET FITTINGS; PUMP CIRCULATION SYSTEMS[2]

Engine Power, b. hp.		
Passenger Cars	Trucks and Tractors	Inside Diameter, in.
Up to 40	....	1
40 to 60	....	1¼
....	Up to 30	1
....	30 to 40	1¼
....	40 to 60	1½

[2]Thermosyphon systems should use fittings of about twice the area of those herein stated.

The amount of heat lost to the water in the jackets varies on different types of engine. The greatest amount of heat, about 40 per cent, is dissipated to the water-jackets on a T-head engine; and the least, about 25 per cent, on a Knight type. The amount of heat dissipated to the water-jackets may vary as much as 15 per cent for the same engine, according to the speed and power developed. The percentage of heat lost to the jackets is the least at speeds around maximum horsepower. At lower speeds the percentage may increase. Water-jacket losses also vary according to the temperature of the water. The higher the water temperature is, the less the water-jacket loss and the mechanical losses become. The mechanical efficiency of the engine may vary as much as 5 per cent, according to the temperature of the water in the jackets.

TYPES OF COOLING SYSTEMS

Some authorities claim that at least 0.3 gal. of water per min. per b.hp. should be circulated through the core; others advocate as high as 0.8. The Bureau of Standards states that at least 2 gal. per min. per ft. of width per in. of depth of core should be circulated. Water circulation should be figured from the amount of heat to be dissipated so that the temperature drop through the radiator is not over 15 deg. fahr.

Fig. 5 shows the effect of water flow on a typical 3-in. core. For this particular core, 30 per cent more heat is dissipated by circulating the water at the rate of 15 than at 7½ gal. per min., indicating that at the latter rate of circulation through the core a 30 per cent larger radiator would be necessary. The greater the flow of water is, the higher the mean temperature of the water entering and leaving the core will be. Heat transfer is directly proportional to the difference between the mean temperature of the water and the atmospheric temperature. Hence, the higher the mean temperature of the water is, the greater the temperature difference between the mean

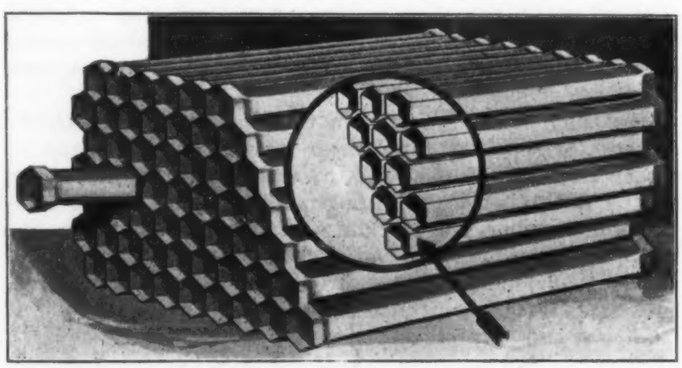

FIG. 4—THE SINGLE-TUBE TYPE OF RADIATOR CORE

temperature and the temperature of the outside air will be. As a result, the heat dissipation will be greater. Radiators should be designed so that they will handle as much water as the pump can deliver; otherwise water will build up in the top tank and run out of the overflow. The average water capacity of some 20 radiator cores made by different manufacturers is 0.00705 lb. of water per cu. in. of core volume.

The thermosyphon cooling system is used principally on small four-cylinder passenger cars and on trucks of capacity not greater than 1½ tons. Table 2 sets forth the number of users of thermosyphon as against pump systems on various sized engines. This list is compiled from statistics secured from some of the best-known motor-vehicle builders of today.

To obtain the most satisfactory results in using a

thermosyphon system, the radiator should be located relatively high in relation to the engine. The flow through the radiator and water-jacket should be as free as possible, and the complete system including the radiator should contain, for the same size of engine, about 1 gal. more of water than a pump system. This is one reason there is an extension tank on the back of the top tank, on radiators to be used in the thermosyphon system. Another important function of the extension tank is to keep a large volume of water above the radiator inlet. If the water level should fall below this inlet, due to evaporation or boiling, the water circulation would be greatly reduced or completely stopped. Larger inlet and outlet fittings are necessary to assure free water flow. About 25 per cent more radiating surface is ordinarily used in a thermosyphon system than is required in the pump circulating system of the same size, due to the low water circulation.

TABLE 2.—THERMOSYPHON COMPARED WITH PUMP-SYSTEM USERS

Size of Vehicle		Number of Users	
Passenger Cars, Number of Cylinders	Trucks, Capacity, tons	Thermosyphon	Pump
4	....	30	15
6	....	10	66
8	....	2	12
12	....	0	5
..	Up to 1½	54	25
..	1½ to 2½	51	132
..	2½ and over	5	208

The possibility of mechanical difficulties with the thermosyphon system is reduced because of its simplicity. Engines cooled by this system warm up more quickly than those using the pump system and, in cold weather, the radiator is less apt to freeze after the engine has stopped. This is because the water continues to circulate through the system until it has cooled down. There is, however, the possibility that in cold weather the radiator will freeze while the car is running, on account of the slow circulation of water through the radiator. There is also a probability of boiling in sustained driving with wide-open throttle in warm weather. Another disadvantage is the large temperature variation between the top and bottom of the water-jacket, a distance of only 5 to 7 in., this being often as much as 80 to 100 deg. fahr.

Air Velocity

One of the most important factors affecting radiator performance is the air velocity through the core. As this is increased, the heat dissipation also increases and, as dissipation increases, a smaller radiator can be used to dissipate the same amount of heat; hence, the cost and weight of the radiator decreases as the air velocity increases. Heat dissipation is generally directly proportional to air velocity through the core for direct-cooling surfaces, but for indirect-cooling surfaces the dissipation does not increase as rapidly as the air velocity. If the heat dissipation for a certain air velocity through the core is known, the heat dissipation at any other air velocity can be found from the following equation:

$$H = h\,(V_2 \div V_1)^c,$$

where

h = the heat dissipation at V_1 air velocity through core
H = the heat dissipation at V_2 air velocity through core
c = an exponent whose value varies from 0.6 to 1.0 depending upon the type of core. A fair estimated average is 0.75 to 0.80

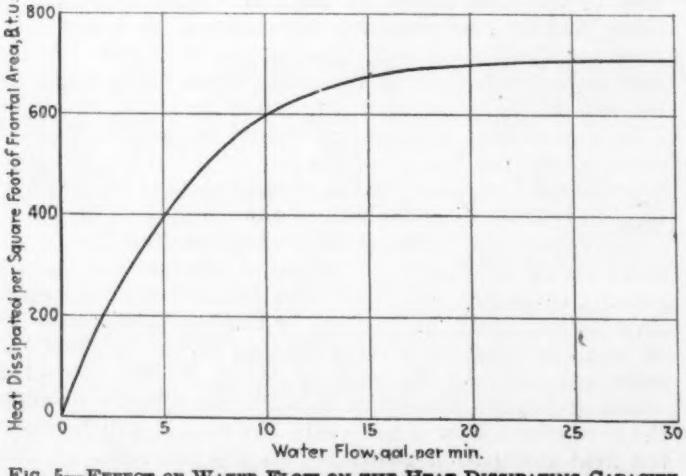

FIG. 5—EFFECT OF WATER FLOW ON THE HEAT DISSIPATING CAPACITY OF A TYPICAL 3-IN. RADIATOR CORE

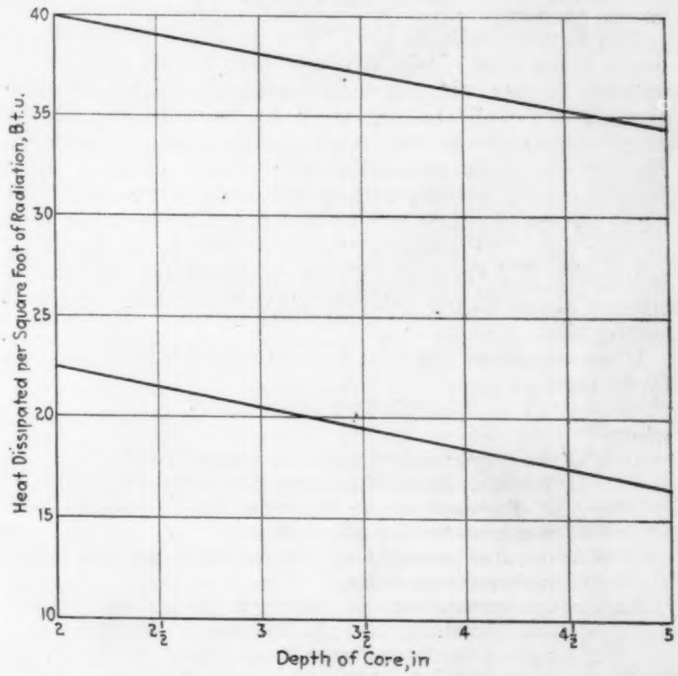

FIG. 6—CURVES SHOWING THE RELATION BETWEEN THE CORE DEPTH AND THE HEAT DISSIPATING CAPACITY

An air velocity through the core of about 1800 ft. per min. is a good standard to maintain for trucks and tractors. Of course, as the depth of core is increased, it becomes more difficult to obtain high air velocity and the radiator becomes less efficient per square foot of radiating surface.

The lower part of Fig. 3 shows the results of tests of a large number of commercial radiators with which an air velocity of 1800 ft. per min. through the radiator has been used as a standard. The upper part of Fig. 3 gives the average heat dissipated per square foot of radiating surface for an air velocity through the core of 4000 ft. per min., which agrees with passenger-car practice. These data can be used as an aid in approximating radiator core dimensions for engines whose heat losses to the jacket-water can be estimated. Radiating surface is here considered as the sum of direct-radiating surface and the indirect surfaces. In either case only the surface exposed to the air is considered radiating surface; of direct surface, only the surface of one side of the metal, and in the case of indirect cooling fin, both sides of the metal if these are exposed to the air. In using the curves of heat

dissipated per square foot of radiating surface it is very important that the radiating surface shall have been computed correctly. The cooling surface of many radiators is greatly overrated.

If the radiating surface increases in direct proportion to the depth of the core, increasing the depth of core increases the heat dissipation as shown in Table 3, according to the curves in Fig. 6 on page 551.

TABLE 3.—INCREASE IN HEAT DISSIPATION

Increase in Depth of Core, in.		Air Velocity Through Radiator Core	
From	To	1800 ft. per min., per cent	4000 ft. per min., per cent
2	2½	19.2	21.8
2½	3	14.1	16.2
3	3½	11.0	14.0
3½	4	8.3	11.8
4	4½	6.3	9.5
4½	5	4.8	8.0

The figures indicate that there is slight advantage in using more than a 4-in. depth of core for an air velocity of 1800 ft. per min. If a 4-in. core should not be large enough, it would be advisable to increase the frontal area. Cores deeper than 4 in. can be used satisfactorily for air velocities greater than 1800 ft. per min. The frontal area of a radiator core should be made sufficiently large for satisfactory cooling and never be less than 8 sq. in. per b.hp. for passenger cars or 11 sq. in. per b.hp. for trucks and tractors. These amounts are usually increased about 25 per cent when thermosyphon cooling is employed.

If we represent the heat to be dissipated by a radiator by H, then

$$H = (K \cdot F \cdot h \cdot \text{b.hp.}) \div 60$$

where

K = the percentage of heat transferred to the water-jackets, depending upon the type of engine. K varies from 40 per cent for T-head to 25 per cent for Knight engines

F = the fuel economy of the engine in pounds per horsepower per hour

b.hp. = the horsepower at governed speed for trucks and tractors; for passenger-car engines it equals the horsepower at an engine speed that is capable of producing a road speed sufficient to create an air velocity through the core of 4000 ft. per min.

h = the heating value of the fuel in British thermal units per pound

If the amount of radiating surface of various depths of core and the total amount of heat to be dissipated by the radiator are known, it is a fairly simple matter to determine the approximate depth of radiator core for an engine that uses a water-pump. The following equation will aid in determining a theoretical depth of core when the air velocity through the core is 1800 or 4000 ft. per. min.

$$H/A \leqq RD$$

where

H = the total amount of heat to be dissipated by the radiator in British thermal units per minute

A = the exposed frontal area of the core, in square feet

R = the square feet of radiating surface of the core per square foot of frontal area

D = the British thermal units dissipated per square foot of radiating surface, from either curve in Fig. 6

This will give only a theoretical depth of core, which may vary greatly from the actual core depth necessary, because the cooling is affected by the design of the various units of the cooling system.

The volume of air necessary to cool a truck or tractor engine successfully is usually about 160 cu. ft. per min. per b.hp. This is based on a temperature rise of air in passing through the radiator of from 25 to 30 deg. fahr. An important consideration affecting this required volume of air is the discharge of the air after it has passed through the radiator into the hood. In passing through the radiator the air becomes heated and expands. The dust-pan and floor-boards restrict a free discharge of the heated air and, unless sufficient hood louvers or other means of escape are provided, a static back-pressure will build up under the hood. The discharge area for the air should be greater than the intake area by at least 20 or 25 per cent. It is a common fault to provide a discharge area less than the intake area. If due consideration is given to the importance of air circulation when designing the cooling system for an engine, some provision will be made for increasing the discharge area sufficiently to allow free escape of the warm air imprisoned under the hood.

Cooling Fans

To assure sufficient air for cooling, it is necessary to supply the cooling system with an efficient fan of correct size and properly driven. Four-blade fans are by far the most popular. This is due to the fact that they can be driven at a slower speed than the two or three-blade fans to deliver the same volume of air. Slower fan speed lessens belt slippage and lengthens the life of the belt. Lubrication and bearing troubles also will be reduced. With six-blade fans, the blades are so close together that at the high speeds often reached in passenger cars cavitation results and the fan loses its efficiency.

Fans are usually made of aluminum or pressed steel. The cast-aluminum fans can be cast so that the blades have a true propeller pitch, increasing their efficiency and requiring less horsepower to deliver a certain volume of air than pressed-steel fans of a similar size. Flat-blade pressed-steel fans are mechanically weaker than the curved-blade fans and, if subjected to high speeds, require a rim around their periphery or grooves in the blade, both of which lower their efficiency. They must be driven at higher speed to deliver the same volume of air, and this is a disadvantage since high-speed fans are usually noisy.

The distance from the tip of the fan blade to the back of the radiator core should be at least ½ in. Fans too close to the core tend to be noisy and to localize the air flow to the area swept by the fan. With reference to truck and tractor practice, the addition of a properly-designed fan-shroud will increase and distribute the air flow more evenly through the core. When using a shroud, the fan should be at least 2 in. from the core, or 2½ to 3 in. if possible. The shroud should be free from sharp corners, and the fan, if of the curved-blade pressed-steel type, should be placed in the shroud so that the back of the fan is flush with the back of the shroud.

Increasing the diameter of average cooling fans 1 in. and keeping the fan speed the same will increase the air velocity through the radiator core from 12 to 15 per cent. This allows either an increase in the heat dissipation of 10 to 13 per cent, or driving the fan slower to effect the same results. An increase of ¼ in. in the projected width of the fan blade will increase the velocity through the core about 3 or 4 per cent; likewise it will increase the heat dissipation about 2½ to 3½ per cent. A fan of large diameter will require less horsepower to deliver

a given volume of air than a fan of smaller diameter, and can be driven at a slower speed. It is important to use fans with as large diameters as possible for efficient cooling of trucks and tractors and the sweep should cover practically the entire radiator core.

To drive a fan with as little belt-slippage as possible, large-diameter pulleys should be used, and the belt width should be ample to carry the load satisfactorily. The diameter of the smaller pulley should not be less than $2\frac{1}{2}$ in. for fans whose diameter is 18 in. or less, nor less than 3 in. for fans of greater diameter.

General Design Factors

Radiator calculation can be no more than an approximation at best, as engines of the same size and type may require different cooling. A change in drivers or operators may have a noticeable effect on the cooling of an engine. Carburetion and ignition timing of course affect cooling. Designers should give the cooling system proper consideration, embodying therein accepted principles. In order that the user may obtain cooling that is as satisfactory a year after as at the time of his purchase, it is necessary that the automotive manufacturer furnish him with instructions as to when and how to clean both the inside and outside of the radiator. A cooling system can be no better than its weakest unit and the designer is urged to bear in mind the importance of each of the units individually.

STANDARDIZATION IN GERMANY

THERE has been formed the Standards Committee of the German Industries (Normenausschuss der Deutschen Industrie) which, though organized less than two years ago, has already published 160 standard sheets and has 400 in process. Unlike the standardization work in the United States the committee is dealing with manufacturing rather than with materials standards, for in the present crisis it is important to effect as quickly as possible such standardization and simplification of design as will save both labor and material. The attack has been begun on design standards, also, because the Germans do not know definitely where some of their raw materials will come from.

The standard sheets already issued cover a surprisingly wide field, from tool grips, gages and wood screws to window frames for small dwellings. Standardization of parts for machine tools, automobiles, agricultural machinery and locomotives is being studied. A subcommittee has in hand the standardization of rolled shapes, while a number of subcommittees are working at high speed on the elements, doors, stairs, roofing, plumbing, etc., of small dwellings, of which there is great shortage in Germany and on which much labor and material must be used as soon as Germany has the financial resources. The cooperation which this committee is receiving is extraordinary, and could not, I was told, have been secured before the war. Now the necessity is such that no one is appealed to in vain.

For furtherance of management studies and exchange of experiences, there has been formed an Association of German Works Engineers. Already there are branches in 15 manufacturing centers, while a dozen questions, such as wage and cost systems, making and use of time and motion studies, have been formulated for study by committees and discussion at meetings. Employment methods, the influence on industry of the standardization of design, the function and place of testing in industrial works, and the layout and organization of factories, are other questions that are being taken in hand. The effects of standardization, of reduction in the number of patterns produced in a given factory, of specialization by shops and individuals, are being carefully studied and both direct costs and the overhead are analyzed.

The Verein Deutscher Ingenieure, an organization of 25,000 members, played a prominent part in the organization of the Standards Committee, and the offices of both bodies are in the society's headquarters at Berlin. The publishing activities of the Verein have been greatly increased. The pre-war publications included the *Zeitschrift* (the proceedings), published as a weekly engineering journal; *Technik und Wirtschaft* (Engineering and Business), a monthly; a Year Book of contributions to the history of engineering and industry, and Forschungsarbeiten (Research Papers), which appear irregularly. Since the war the following publications have been started: *Der Betrieb*, which discusses all phases of industrial management and is the medium for the announcements of the Standards Committee; *Technik in der Landwirtschaft*, a monthly devoted to the applications of engineering to agriculture, and *Technische Zeitschriftenschau*, a monthly digest of engineering publications.

German technical development in the next 10 years will deserve the very closest study. German industrialists and engineers in the 30 years following the Franco-Prussian war changed Germany from an agricultural to an industrial nation. The genius, the patience, the perseverance, the thoroughness that created that economic revolution are still to be found in Germany. If before the war Germany's technical progress was rapid, it will now, under the new conditions, be so accelerated that we can safely look for extraordinary technical progress in the near future. From the engineering standpoint Germany in the next decade should be the most interesting country in the world.—E. J. Mehren in *Engineering News-Record*.

ALKALINE WATER AND RADIATOR CORES

THE Society received a letter recently from the chief engineer of a prominent automobile company making inquiry about the effect of alkaline waters and air in the Far West upon brass radiator cores and tanks. This letter was submitted to H. C. Harrison, president of the Harrison Radiator Corporation, who offered the following information which is considered of sufficient interest to the membership to be published in The Journal.

He stated that, on the Pacific coast and particularly in the States of Missouri, Kansas, Oklahoma, Colorado, Utah, Nevada, Arizona and California, brass radiator cores gave trouble due to corrosion and generally had to be replaced inside of 12 months. Because of this a large trade has been developed on the Pacific coast among small radiator makers who replace the standard cores with copper ones of their own manufacture. It was suggested that cars operating in these localities be equipped with copper cores and tinning the top headers of the radiator, even though it is of the cellular type, since the worst corrosion seems to occur on the bottom surface of the top tank. The substitution of copper for brass does not entirely eliminate the trouble due to corrosion, but it greatly prolongs the life of the radiator. The effect of the corrosion is much the same as in the case where mineral non-freezing solutions are employed in radiators. It is curious that most car builders as well as their service departments are ignorant of these conditions, in spite of the fact that corrosion of this character is so common that the life of a radiator has been accepted in these sections as necessarily limited to a period which is very much less than the life of the car.

RETURN OF THE ALASKAN EXPEDITION

THE Alaskan flying expedition has made its contribution to the history of aviation. The 9000 miles from New York to Nome and return has been cut to approximately 110 flying hours. The greatest pioneering feat attempted by the Army Air Service ended successfully when the four DH-4 planes, running their original engines, landed at Mitchel Field, Mineola, N. Y., on the afternoon of Oct. 20, having been escorted from New York City by an aerial fleet.

After a night's rest, the officers and men comprising the expedition proceeded, on the morning of the 21st, to Washington, where a reception was accorded them befitting an occasion so notable in the history of aviation. Flying a DH-4 plane, Gen. Charles T. Menoher, chief of the Army Air Service, met the party in the air and escorted them to Bolling Field. Also in the receiving party were Gen. William Mitchell, chief of training and operations, commanding the 99th and the 10th Observation Squadrons, and Col. William H. Hensley, Jr., the foremost airship pilot in America, who crossed the Atlantic in the British R-34, commanding the U S ZD No. 1, flying up from Langley Field with a full crew of 24 officers and men. Each squadron consisted of 18 planes flying in vee formation, making a total of 54 Army planes, in addition to which were a number of civilian aircraft which took the air to honor the return of the intrepid aeronauts.

The aviators told many interesting stories of their trip. At some landing places along the way game was plentiful and fresh meat was always available. The fliers sighted herds of reindeer and caribou, and often saw bear, mountain sheep and other game. A school of white whales and many seals were sighted in the Bering Sea. Capt. St. Clair Street said that the expedition failed to obtain as many pictures as they had hoped because of poor visibility. In bad weather it was necessary to fly high to avoid hitting mountain peaks, a good portion of the journey having been made at an altitude of 8000 ft. Hundreds of miles of the territory covered had not been mapped, and the only information available was what could be had from trappers.

Captain Street, piloting plane No. 1 and in command of the expedition, was stationed at the training camp at Issoudun, France, during the war, being one of the first aviation officers sent overseas. He was decorated by General Pershing. Sergt. Edmund Henriques, his mechanician, is one of the most experienced men in the service. Plane No. 2 was piloted by First-Lieut. Clifford C. Nutt and Second-Lieut. Eric C. Nelson, engineering officer. A year ago these two officers made a successful recruiting flight from Houston, Tex., to San Diego, Cal., by way of Omaha, Neb., and Denver, Colo., and return, a journey of 7000 miles, without accident or mishap of any kind. Lieut. C. H. Crumrine, the photographic officer, piloted plane No. 3 with Sergt. Albert I. Vierra, one of the most experienced Liberty engine experts, as mechanician. Lieutenant Crumrine is an experienced pilot, having been stationed at Carlstrom Field, Florida. He will be remembered through his connection with the finding of Lieutenant Niergarth, the airman who was lost in the Everglades. Lieut. Ross C. Kirkpatrick, who made a distinguished record in the transcontinental endurance and reliability flight, the information officer of the expedition, piloted plane No. 4, with Joseph E. English as mechanician.

COMPARISON WITH OTHER LONG-DISTANCE FLIGHTS

The Alaskan Flying Expedition successfully completed one of the most hazardous and stupendous aerial events yet attempted in any country. When it is considered that these fliers had to proceed over at least 2000 lineal miles of virgin territory far remote from habitation, without a landmark to guide them or a field upon which to alight, over jagged mountain peaks and endless snow-covered glaciers, and over 7000 miles of country, encountering the greatest menace to airmen, fog, yet pushing dauntlessly on against all kinds of odds, one must conclude that this was one of the greatest efforts of pioneering work yet accomplished by the Army Air Service.

The British last spring attempted to fly from Egypt to the Cape, over the wilds of Africa. One pilot reached the destination, but only after he had replaced his machine and engines, and after much delay and inconvenience. In the Alaskan flight, on the other hand, thanks to the efforts of the commander, Capt. St. Clair Street, and the personnel of his party, despite discouraging delays and the worst possible weather conditions the expedition pushed on and on, flying successfully the same planes with the same engines a distance of 9000 miles, with scarcely a change of spare parts or equipment throughout. In the transcontinental reliability test last autumn, Lieut. Belvin Maynard, the winner, broke his engine near Omaha, and had to change it entirely before proceeding. Only one Liberty engine succeeded in making the journey both ways, and this was piloted by Lieut. E. A. Manzelman, who felt that by nursing it along and caring for his machine, as such a fine piece of mechanism as an airplane should be cared for, he would gain a victory more pronounced than the saving of a few moments of time with the sacrifice of a valuable engine.

Compared to the non-stop flight made by the Englishman, John Alcock, which gained for him recognition from the British Government in the form of knighthood, most fliers will agree that the Alaskan flight is a greater feat. Alcock's undertaking, though marvelous and unprecedented, was, to a certain extent, a wager wherein the stakes and the odds were great, but the effort was only 16 hr. continuous flying with the chance of a failing engine. The Alaska flight was a steady grind of over three months' duration. Only those who have flown on expeditions of this nature can appreciate the state of mind of the pilots as they awoke each morning to realize the hazardous undertaking they had attempted and the long day's flight over uncharted airways before them.

Compared to the flight of the NC-4 across the ocean, the Alaskan expedition ranks high. Commander Read had only one landing to make, at the Azores. Captain Street and his men were compelled to land fifty times on strange fields and in one instance on wholly impossible ground. To reach these fields successfully was a big task in itself, but to land an airplane without crashing was a problem that did not appear in the NC-4 flight. It took skill, courage and determination to fly to Nome and back.—Air Service News Letter.

POWER REQUIRED TO DRIVE MAGNETOS AND GENERATORS

THE Air Service recently issued serial report No. 1281, of the Engineering Division at McCook Field, which presents and analyzes the results of a test to determine the horsepower required to drive the generator on the Liberty engine. Two different makes of magneto were also tested for the same purpose. The units under test were connected to a 5-hp. electric cradle dynamometer and the torque required to drive them noted. A load was placed on the magnetos by connecting ¼-in. spark-gaps in series with them. The generator was loaded by a slide-wire resistance connected in series. Although the magnetos were driven at speeds up to 3300 r.p.m., the torque required was too small to measure. The power absorbed in driving the generator ranged from 0.07 hp. at 1800 r.p.m., under a load of 1 amp. to 0.19 hp. at a generator speed of 3300 r.p.m. when loaded to 4 amp. This power is much less than that absorbed by the water and oil pumps and is also insignificant when compared with the total horsepower of any aviation engine. These data are of value when the strength of the parts driving these engine accessories is being considered.

METHOD FOR IDENTIFYING STEEL STOCK

THE Miscellaneous Division of the Standards Committee is considering the adoption of a system of identifying marks for S. A. E. steels employing steel letter dies. Numerous other systems have been considered in the past. Most of these involved the use of colors to be painted on the bars, billets or other forms of steel. Such systems are unsatisfactory because (*a*) only a very limited number of readily distinguishable, fast colors are available; (*b*) paint chips off and discolors when rust develops under it on steel exposed to weather and (*c*) paint cannot be applied to hot bars or billets.

The system of marking with steel letter dies can be expanded to take care of any number of steels. The choice and arrangement of letters are such that ambiguity is impossible. Similar letters such as *N* and *Z* are not both used. The symbol *BC* is employed, but the symbol *CB* is not used, etc., thus avoiding confusion which would occur should letters be applied upside down. Rust will affect die-marks far less than paint. Hot steel can be easily marked with letter dies.

IDENTIFYING MARKS FOR STEEL STOCK

S. A. E. Steel No.		*Identification*
	Carbon Steels	
1010		AA
1020		BB
1025		A
1035		B
1045		C
1095		AB
	Screw Stock	
1112		D
1120		E
	Steel Castings	
1235		CC
	Nickel Steels	
2315		H
2320		I
2330		K
2335		L
2340		M
2345		N
2512		O
	Silico-Manganese Steels	
9250		AL
9260		AM
	Nickel-Chromium Steels	
3120		P
3125		R
3130		S
3135		T
3140		U
3220		V
3230		X
3240		Y
3250		DD
3415		EE
3435		HH
3450		II
3320		KK
3330		LL
3340		MM
	Chromium Steels	
5120		NN
5140		OO
5165		PP
52100		RR
	Chromium-Vanadium Steels	
6120		SS
6125		TT
6130		UU
6135		XX
6140		YY
6145		AC
6150		AD
6195		AE
	Tungsten Steels	
71360		AH
71660		AI
7260		AK

It is well to bear in mind that this system would be adopted only as S. A. E. Recommended Practice and need have no effect on any other systems in use. It is suggested that every member of the Society, who is interested in this subject, give it study. Comments and criticisms based upon experience and not mere opinions should be sent to the Society office promptly. The proposed system will be recommeneded for adoption as S. A. E. Recommended Practice by the Miscellaneous Division unless adequate valid objections are received.

RUBBER ARMOR FOR AIRPLANE GASOLINE TANKS

RUBBER was long ago suggested as a possible defensive armor for battleships, the idea being that many projectiles would not penetrate it owing to rebound and deflection, and that holes made by those which did pierce the rubber would quickly and almost completely close again. While this dream has never materialized, gasoline tanks on United States Army airplanes are being equipped with rubber and fabric coverings to prevent leaks in case the tank is penetrated by bullets and thus the fire hazard is reduced. There are two types of these leak-proof coverings, detachable and fixed, the former being furnished whenever practicable.

The tank or tank form is first covered with tire breaker fabric with the coated face outside. A 1/16-in. ply of pure first-grade washed and dried smoked sheet rubber is then applied over the breaker fabric. Over the crude rubber is applied a ⅜-in. layer of rubber compound, and the three layers are rolled down into close and uniform contact over the whole surface of the tank, when the completed covering on the tank or form is vulcanized and the accessory fittings for filling the tank are installed. All openings for accessory fittings are reinforced with fabric strips or washers.

Coverings of the detachable type have four triangular end-flaps laced together which permit insertion or removal of the tank. Attached along the edges of these flaps before vulcanization are strips of 17¼-oz. tire duck. These fabric strips are to reinforce the edges which hold the lacing eyelets, which are standard brass grommets. The rubber compound from which the main body of the rubber covering is made contains not less than 92 per cent by weight of new washed and dried hard fine Pará, or the highest grade only of new Hevea plantation rubber, 6 per cent of sulphur and not more than 2 per cent of magnesium oxide.

The required tensile strength of the compound is at least 1800 lb. per sq. in. The elongation of a 2-in. section at the breaking point is at least 700 per cent. When the specimen is stretched from 2 to 15 in., held in the stretched position for 10 min. and then released for 10 min., the permanent elongation must not exceed 12½ per cent. Great care is exercised during the whole manufacturing process to exclude grit, dust or foreign substances from the interior of the tank. Tensile test-specimens of the rubber compound are cut with a die from samples furnished by the manufacturer, or from a sample covering. Samples are required to be approximately 3/32 or ⅛ in. thick with the constricted portion of the specimen ¼ in. wide and having smooth edges.—*India Rubber World.*

Fuel Mixtures on London Omnibuses[1]

By G. J. SHAVE[2]

THE experiments covered by this paper were carried out with a view to ascertaining the most suitable mixture of benzol-alcohol for use in standard buses with B type engine. The production of benzol is limited by the amount of coal used for gas and metallurgical coke-making. Raw material for the production of alcohol is practically limitless. Under these conditions it was felt desirable to find the largest proportion of alcohol that could be reasonably used, with due regard to fuel economy and the minimum of alteration in converting a standard gasoline engine to burn this fuel. Gasoline is necessarily taken as a standard of comparison.

Compared with gasoline, benzol and alcohol are slow-burning fuels. Consequently compression has to be increased in proportion to the slowness of burning, and within the limits of the detonating temperature of the fuel and air mixtures. Table 1 gives the calorific values and specific gravities of the fuel consumption.

TABLE 1—CALORIFIC VALUES AND SPECIFIC GRAVITIES

	B.t.u. per lb.	Specific Gravity at 60 deg. fahr.	B.t.u. per gal.
Gasoline	19,705	0.7680	151,305
Benzol	17,932	0.8720	156,367
Alcohol	11,952	0.7820	93,465
50 per cent Benzol and 50 per cent Alcohol	14,906	0.8380	124,916
65 per cent Alcohol, 30 per cent Benzol and 5 per cent Ether	13,410	0,8265	110,816

Though benzol stands the highest in British thermal units per gallon, the difference is very small, and it follows that it is possible to run a gasoline engine on benzol without altering the compression, though to obtain the best results a different carbureter setting is required. With alcohol, however, owing to its slow combustion, it was found that good results could be obtained only by raising the compression considerably. In connection with these fuels, another point is the temperature in the intake pipe, which should be maintained high enough to insure complete vaporization of the fuel.

Pure benzol or power-alcohol can be used as fuel, and every proportion of mixtures between the two. A mixture of approximately 92 per cent benzol and 8 per cent alcohol gives the same value in British thermal units per gallon as gasoline; so it is possible to use on a gasoline engine a mixture that can compare favorably with gasoline without changing the compression or carbureter setting.

BENCH, ROAD AND SERVICE TESTS

Experiments commenced with a 50-per cent mixture. Compared with gasoline, its heat value was as 12.5 to 15, a difference warranting change in compression and carbureter setting. Some fifty bench tests were made on 110 x 140-mm. (4.34 x 5.50-in.) B type engines with a dynamometer. The compression, carbureter setting and intake pipe heating were the variable factors, and it was found that with a 50-per cent mixture a 123-lb. compression gave best results. The most suitable valve-setting was that used in standard B type engines burning gasoline. Exhaust gas analyses showed a complete absence of carbon monoxide with a slight excess of oxygen, indicating that combustion of the fuel was complete.

Further tests investigated the possibility of running standard B type engines with higher compressions on fuels having higher alcohol percentages. During these tests the large range of air and fuel mixtures on which the engine could run was particularly evident. This was more noticeable with alcohol in large proportions, proving conclusively the serviceability of fuels containing alcohol. In these tests the full-load fuel consumption in British thermal units per brake horsepower decreased as the percentage of alcohol increased up to the point at which compression ceased to be sufficiently high; i. e., mixtures containing up to 70 per cent or 80 per cent of alcohol. Half-load consumption gradually, and quarter-load rapidly, become greater. This points to the effect of the low compression due to small throttle openings, and it is suggested that the advantages gained at full throttle will be reduced at decreased throttle openings when using higher percentages of alcohol, especially on the type of engine under trial. It is contended that the higher the compression the worse effect will the pockets have on fuel consumption, more especially at small throttle openings.

The higher the alcohol percentage, the more important is it to design the engine for special purposes. A slow-burning fuel like alcohol makes possible high thermal efficiencies and great fuel economy, but for best results it must be designed to suit the fuel. Generally speaking, such an engine would have a long stroke, high compression and overhead valves, while the importance of sufficient heat to vaporize the mixture cannot be exaggerated. To summarize these tests

(1) The greater the alcohol percentage the higher the possible thermal efficiencies for the same compression
(2) The greater the alcohol percentage the higher can the compression be raised, with consequent rise in thermal efficiency
(3) With high compression the ill effects of valve-pockets are more noticeable at small throttle openings than with low compression

The chassis with which these tests were made was a bus chassis fitted up as a motor truck. Engine compression was raised to 160 lb. per sq. in. by riveting dome-shaped aluminum plates on top of the pistons to follow roughly the contour of the cylinder-head. The following mixtures were tried:

Alcohol, per cent	Benzol, per cent	Calorific Value B.t.u. per gal.
90	10	100,000
80	20	109,487
70	30	115,347
60	40	120,207
50	50	127,063
Gasoline		151,305

The best all-round results were obtained with a 70-30 per cent mixture, though a 50-per cent mixture gave very good results. Comparing the 70-per cent or high-compression mixture and gasoline normal compression we get the following results:

	British Thermal Units Mixture	Per mile Gasoline	Saving of per cent
Bench Test	12,160	16,100 (normal speed)	24.5
Road Service Test	14,100	15,810	10.8

After running for a month on 50-per cent benzol-alcohol fuel, the tank, a new one, was found to have become porous and corroded from the action of the fuel. Laboratory experiments showed that copper and iron are attacked badly by these fuels; brass, zinc, tin and aluminum are slightly attacked; lead is immune. Fuel tanks and pipes should therefore be lead-coated. A sample of sheet iron suitable for tanks is coated with an alloy composed of 20 per cent tin

[1]Abstract of a paper read before the Fuels Section of the Imperial Motor Transport Conference, at the Royal Automobile Club, London, Oct. 18, 1920.
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and 80 per cent lead. On brass the effect is so slight that the carbureter can still be made of that metal.

The results in service are given in the accompanying table.

TABLE 2—FUEL CONSUMPTION

Fuel Composition Alcohol, per cent	Benzol, per cent	Bus No.	Miles per gal.	British Thermal Units per mile
25	75	B-908	7.42	18,980
5	95	B-415	7.60	20,150
20	80	B-849	7.28	19,780
50	50	B-1263	7.00	17,816

[3]For the week the first two mixtures were tested, the fleet which used gasoline averaged 7.58 miles per gal. and 19,900 B.t.u. per mile; for the week of the last two mixtures the corresponding figures were 7.55 miles per gal. and 20,050 B.t.u. per mile.

It is seen that 50 per cent mixture gives the greatest efficiency, consuming some 12½ per cent less British thermal units per mile than gasoline.

After six weeks' service, the engine running on the 50-per cent mixture was examined after a concluding test that showed a somewhat increased fuel consumption and decreased brake horsepower. One cylinder was found badly scored by a piston-pin. The inlet-valve pockets, as far as 1 in. under the valve heads, were coated with a thick tar-like substance partially choking the passage. There was also a little of this tar-like deposit in the inlet manifold. Exhaust valves were clean and in good condition, nor was there much deposit on the pistons. The partial choking of the inlet-valve openings would probably account for the decreased horsepower.

Though this points to the desirability of examining valves and intake pipe periodically, no ill effects were noticeable in running in service; in fact, the miles per gallon were fairly well maintained, ease of starting, acceleration and flexibility were very noticeable, knocking and pinking were not existent on hills at low speeds. This is due to the combustion being more sustained and the absence of tendency to preignition or detonation. Further tests of 14 buses in service showed an average consumption of 7 miles to the gallon during six weeks working of over 4500 miles. At the same time, for the same period, the average on gasoline was 7.5 miles per gal. These tests emphasize the influence of colder weather, indifferent quality of benzol and the need for separation of water from the alcohol; these points contributed to lower the economy as compared with the figures originally obtained. The excess of water may have been due to colder weather and more humid atmosphere. It made the bus difficult to start and caused trouble by the condensation of water on the spark-plugs. The latter objection, however, was overcome by using plugs with the porcelain insulation extending to within a short distance of the electrode. To eliminate the difficulty a drain-tap was fitted to run off the water before starting in the morning. As an explanation of this collection of water, it is suggested that alcohol, benzol and water are not completely miscible at low temperature.

The average fuel consumption for approximately a half dozen buses using the 50-per cent mixture in the winter was 6.05 miles per gal., while the average for the fleet using gasoline was 7.19 miles per gal. The corresponding figures for summer were 7.00 and 7.55 miles per gal.

Comparative Cost

It is difficult to estimate the economy in comparing these figures, as fuel is purchased by the gallon and not on the British thermal unit basis. Moreover, the heavy Government duty on alcohol stands in the way of a comparison. On the basis of equal cost, say 25d. per gal., we get the following comparisons:

	Gasoline	50-Per Cent Benzol-Alcohol Mixture
British thermal units per penny	6,050	5,000
British thermal units per mile	20,050	17,816
Cost per mile	3.3d	3.5d

This accords gasoline 20 per cent more heat value per penny than the 50-per cent mixture, but the latter is 12 per cent more economical. On cost, however, gasoline would be 8 per cent the cheaper fuel, assuming equal cost per gallon. Apart, however, from the question of heat economy, the engine ran very much better on the mixture than on gasoline.

Experiments with the alcohol-benzol mixtures have now been discontinued, and mixtures of alcohol and ether and alcohol, benzol and ether are under investigation. Tests are not very far advanced, but some data of bench tests can be given. The fuel was prepared from denatured alcohol, benzol and methylated ether. The mixture has the following composition: Alcohol 65 per cent, benzol 30 per cent and ether 5 per cent (specific gravity 0.8625 at 60 deg. fahr.). Three types of intake pipe were used; the plain, exhaust-heated and water-jacketed. The last gave the best, the exhaust-heated pipe the worst, results. With plain or water-jacketed intake pipes, starting from cold was easy, though in the last case steady running was not obtained until the engine had become hot.

Compared with gasoline, the power at speeds below 900 r.p.m. is slightly better; at high speeds it falls off. Consumption is, however, slightly higher with this mixture than with gasoline, this being more marked at quarter load. From 360 r.p.m. acceleration was good in all cases, and there was a complete absence of knocking and pinking. Exhaust-gas analyses showed a satisfactory absence of carbon monoxide, indicating that the combustion was complete, and only the slightest deposit was noticed on plug and valve caps. Also there was no objectionable smell from the exhaust.

We are fast squandering the oil that has been stored in the fuel beds and it seems so far as our present knowledge takes us that it is to the fuels experimented with that we must turn for our salvation.

QUANTITY PRODUCTION

A CAR contains about 3000 component parts, some of these taking as many as 30 different operations to produce them from the raw metal. Under a scheme of mass production many hours of thought must be applied to each particular operation, to design the tools, jigs and fixtures required for interchangeability. The expense of providing the best possible means of manufacture at each of these numerous stages could only be undertaken for large quantities. Each stage develops its own specialists, concentrating on one operation year in and year out, and attaining a degree of skill in workmanship such as can only be attained by this experience. The work, divided and subdivided, is again checked at each stage by its specialists, each of whom has a very highly trained faculty for detecting inaccuracies in that particular job. No group of workers on the old lines could compete with these single-operation specialists. The same general principle applies to the machines. In a mass production scheme it pays to introduce single-purpose machinery, and these machines do their work very much better. It is obvious that a lathe used for removing large quantities of material, for finishing operations and for general work, cannot retain the accuracy of a machine specially made and constantly used only for removing a few thousandths of an inch on a final finishing operation of one particular part. The machinery is better, the men are better and, finally, to reverse the usual order, the materials used are of better quality than those employed on a mass production job.—E. H. Morris in *The Motor*.

Current Standardization Work

THE pamphlet containing the reports of the Divisions to the Standards Committee covering the work accomplished in the last half of 1920 will be sent to the members prior to the Standards Committee Meeting in January so that they can carefully consider the various recommendations in time to submit comments or criticisms for consideration at the meeting. The Division reports will consist of complete and concise statements of the practices and constructions as recommended together with such illustrations and explanatory remarks as may be necessary.

Progress made by the Standards Committee during the last month is briefly outlined below.

Ball and Roller Bearing Division

At a meeting of the Ball and Roller Bearing Division held at the Society offices on Nov. 10, several recommendations calling for revisions of present standards were adopted. The Division recommended that the present S. A. E. Standard for Angular Contact Ball Bearings, S. A. E. Handbook, Vol. I, page 29ce, should be extended to include tolerances for the overall width of the bearings as follows:

Nos. 200 to 212, or 300 to 312, or 403 to 412—plus or minus 0.003 in.

Nos. 213 to 216, or 313 to 316, or 413 to 416—plus or minus 0.005 in.

Nos. 217 to 222, or 317 to 322, or 417 to 420—plus or minus 0.010 in.

It was also recommended that the width tolerances of the individual rings should be the same as the width tolerances of corresponding sizes of annular ball bearings of the light, medium and heavy series and that the three series of angular contact ball bearings should be published in the S. A. E. Handbook on separate pages.

In reference to the present S. A. E. Standard for Extra Wide Type Angular Ball Bearings, S. A. E. Handbook, Vol I, page 29cd, the Division recommended that this should be revised as follows:

> The title "Extra Wide Type" changed to "Wide Type". The note, "The inside and outside diameters for the different size bearings shall correspond to the inside and outside diameters of the corresponding annular ball bearings of the light, medium and heavy series," added.
>
> The footnote referring to the title, "Normally a double-row type of construction" added.

In the present S. A. E. Standard for Separable Type Annular Ball Bearings, S. A. E. Handbook, Vol. I, page 29cc, it was recommended that the heading for the width column should be changed from "Width of Individual Rings" to "Overall Width"; that tolerances of plus or minus 0.002 in. should be placed on the overall width; and that the footnotes "Individual ring tolerances: plus or minus 0.001 in.", and "Nominal width of individual rings shall be the nominal width given in the table", should be added.

At a meeting of the Division held early in 1920 a Subdivision was appointed to formulate for publication in the S. A. E. Handbook general information covering desirable practice as to shaft and housing fits and tolerances for ball bearings. The Subdivision reported at this meeting a definite recommendation covering shaft tolerances and housing bore tolerances which were considered suitable for automotive application. The recommendation was based on a careful analysis of the press-fit allowances recommended by manufacturers of ball bearings and an investigation of the practices usually followed by the automobile manufacturers. As it was found that the practice of grinding shaft seats was very generally followed, the recommendation was based on this method of finishing the shafts for the application of ball bearings.

The subject of clutch-release bearings was discussed, the Transmission Division having recommended that the Ball and Roller Bearings Division should establish a standard for these in case it should be found that suitable bearings for this type of application were not included among the present thrust-bearing standards. A report is to be prepared covering this subject for the next meeting.

Electrical Equipment Division

The Electrical Equipment Division has recommended that the present standard for Flexible-Disc Magneto Couplings be revised by increasing the outside diameter of the disc from 2¾ to 3 in. and the bolt-circle diameter from 2 to 2¼ in. The reason for increasing these dimensions is to prevent the couplings from tearing at the bolt-holes, this trouble having been experienced in practice.

The Division has considered the adoption of a specification for the testing of spark-plugs. Considerable attention was given to this subject in cooperation with the Motor Transport Corps, as a result of which the latter adopted a definite specification for use in the purchase of spark-plugs. This was printed in the May, 1920, issue of The Journal on page 281. The specification was not however suitable for adoption as standard practice and the Subdivision has therefore formulated the following test which can be applied without the use of expensive test equipment.

> A sufficient number of sample spark-plugs drawn at random from stock are to be furnished to equip at least two of the engines under consideration
>
> The spark-plugs submitted for test must conform in all important dimensions to the engine builder's drawings
>
> Preignition and leakage tests are to be made in the following manner. An engine of the type for which the plugs are intended shall be equipped with a set of the spark-plugs to be tested. The spark-plug gaps shall be carefully adjusted with a suitable thickness gage to the desired dimension and these gaps shall not be disturbed throughout the tests. The engine shall then be coupled to a suitable dynamometer and the circulating water maintained at a temperature of not less than 40 deg. fahr. or more than 60 deg. fahr. The engine shall then be started up and as rapidly as possible brought to the speed corresponding to the maximum torque, the throttle and the spark adjusted for this condition, and the circulating water temperature brought up to a temperature of not less than 190 deg. fahr. nor more than 210 deg. fahr. as rapidly as possible and this temperature maintained for the remainder of the run. Torque and speed readings shall then be taken at 30-sec. intervals for a period of 15 min. Appreciable loss of torque or speed, missing or backfiring which can be attributed to the spark-plugs, will be considered grounds for rejecting the spark-plugs under test, provided the engine is of proved design and has previously demonstrated its ability to run steadily under these conditions. During this run, tests for gas leakage shall be made by covering all joints of the spark-plugs with oil and inspecting for leaks.
>
> Following this 15-min. run at the speed corresponding to maximum torque, the engine shall be brought up to the speed corresponding to maximum horsepower and be held at this speed for not less than 5 min. Observations similar to the previous will be made during this run
>
> Spark-plugs which have successfully passed the

above tests will be considered satisfactory for use insofar as the following points are concerned

(1) Breakage owing to sudden temperature changes
(2) Liability to cause preignition
(3) Leakage
(4) Power performance
(5) Permanence of gap

The following procedure for determining the relative susceptibility of the spark-plugs under test to fouling is intended to serve merely as a guide in making such tests, since general engine influences and more particularly lubrication and carburetion conditions varying as they do in different makes of engine, prohibit the setting of one strictly standard method applicable to all engines.

The engine equipped with the spark-plugs under test shall be run on the dynamometer with the circulating water at not less than 40 deg. fahr. nor more than 60 deg. fahr. The inlet manifold shall be kept at as low a temperature as practicable, all heating means being disconnected so far as possible. The engine shall be run with no load and a wide-open throttle, the speed being held down to between 1000 and 1500 r.p.m. by causing the carbureter to feed an abnormally rich mixture. The engine shall be run in this manner for 3 min., following which the carbureter adjustment shall be restored to standard condition and the load applied to hold the engine at a speed of about 1200 r.p.m. It is assumed that the torque which is to be expected of the engine under test at this speed, has been previously determined. At the end of 2 min. running after applying the load as above explained, the percentage of standard torque which the engine is capable of developing will be considered as a figure of merit for the spark-plugs under test. For instance, if at the end of 2 min. operation under load following the "choked" run, the engine is capable of pulling its standard torque, the spark-plugs shall be considered 100 per cent satisfactory in this regard. If, however, the engine pulls but one-half its regular torque, the figure of merit will be 50. These tests should be repeated a sufficient number of times to insure a consistent average result.

The Bureau of Standards has issued the final revision of the Specifications for Starting and Lighting Storage Batteries for Military and Truck Service, prepared by the Bureau with the cooperation of manufacturers and the Electrical Equipment Subdivision on Storage Batteries. The specification is given below.

Specifications for Starting and Lighting Storage Batteries for Military Automobile and Truck Service

Type of Battery

The battery shall be of the lead-acid type, using flat pasted plates and shall be constructed to withstand hard mechanical service conditions.

Capacity and Arrangement

Medium and Heavy Trucks

Number of Cells	Minimum Capacity, amp-hr.		Maximum Overall Dimensions			Assembly
	5-hr. rate	20-min. rate	Length,[1] in.	Width, in.	Height, in.	
3	60	31	10¾	7½	9⅞	Side to side
3	72	37	11⅛	7½	9⅞	Side to side
3	80	35	14⅛	7½	9⅞	Side to side
6	48	25	17½	7½	9⅞	Side to side
6	50	24	19¾	7½	9⅞	Side to side

[1]No allowance made for hold-down clamps.

Passenger Cars and Light Trucks

Number of Cells	Minimum Capacity, amp-hr.		Maximum Overall Dimensions			Assembly
	5-hr. rate	20-min. rate	Length, in.	Width, in.	Height, in.	
3	60	31	9¾	7½	9⅞	Side to side
3	72	37	11⅛	7½	9⅞	Side to side
3	84	43	12⅝	7½	9⅞	Side to side
3	96	50	13¾	7½	9⅞	Side to side
3	95	43	15⅜	7½	9⅞	Side to side
3	84	43	20⅝	4¾	9⅞	End to end
3	95	43	20⅝	5⅝	9⅞	End to end
3[2]	90	45	18⅞	5½	11¾	End to end
6	36	19	13¼	7½	9⅞	Side to side
6	48	25	15⅜	7½	9⅞	Side to side
6[2]	60	31	17¾	7½	9⅞	Side to side
6[2]	48	25	20⅝	5¾	9⅞	End to end

[2]Not to be continued as a standard size beyond present requirements.

Construction

Connecting straps shall be of lead or lead-antimony alloy. Plates of like polarity in each cell shall be integrally burned to the respective straps. Straps are to be of pillar-post type of sufficient size and strength to be an adequate conductor and support for the group of plates.

Intercell Connectors are to be of the "burned-on" type. The voltage drop in the intercell connectors is not to exceed 10 millivolts per inch of distance between post centers, when discharging at the 20-min. rate. Copper straps, when used, are to be lead-coated and provided with terminals of lead or lead-antimony alloy, which are burned to the posts. Intercell connectors must not obstruct the filling apertures.

Plates shall be of good design and the best quality of materials and workmanship. This is to be judged either by laboratory tests or by a record of satisfactory field service at the option of the purchaser.

Separators shall be (*a*) of properly treated wood corrugated on the side next to the positive plate; or (*b*) of properly treated wood as specified in (*a*) plus a perforated or slotted separator of thin flexible hard rubber, placed between the positive plate and the ribbed side of the wood; or (*c*) of an approved rubber type. The separators are to be held in place by suitable hold-downs.

Terminal posts shall be plainly marked with the polarity as follows:

The positive terminal shall be marked *POS* or *P*
The negative terminal shall be marked *NEG* or *N*

The terminal posts are to be in accordance with the S. A. E. Standard for taper posts as follows:

Small diameter, negative post, in.	⅝
Small diameter, positive post, in.	11/16
Taper per foot, in.	1 1/3
Minimum length of taper, in.	11/16

Sealing nuts or other suitable means are to be used to prevent leakage around the terminal posts of the individual cells. If metallic sealing nuts are used, it is required that they be of lead-antimony alloy throughout.

Jars are to be of hard rubber and to conform in dimensions, design and quality to the Standardization of Hard Rubber Storage Battery Jars for Starting and Lighting Batteries prepared for the Hard Rubber Division of the War Service Committee of the Rubber Industry adopted Aug. 27 and Aug. 28, 1918.

Covers are to be of a good quality of hard rubber. They are to be flat-top and bottom, or molded with flat top, free from acid pockets, with single sealing flange. The cover of each cell is to be provided with a filling aperture closed by a vent-plug of hard rubber. The vent-plug may be of the bayonet or screw type. Each vent-plug is to be provided with an outlet for the gas and a baffle-plate or equivalent means to prevent slopping of the electrolyte, or the escape of spray.

Covers for cells of the batteries specified as for medium and heavy truck service may be of the double-flange type. They are to conform otherwise to the requirements of this section.

Sealing compound shall be of an acid-proof material that will adhere firmly to both rubber and wood surfaces, and of such consistency that it will not flow at 55 deg. cent. (131 deg. fahr.) and will not crack, or separate from the rubber at a temperature of 20 deg. cent. (-4 deg. fahr.) under static test. The sealing compound must not be easily ignited.

Trays shall be of close-grained seasoned hardwood, such as oak, maple, birch, etc., free from knots, checks or other imperfections, up to the standard known as No. 1. Ends are preferably to be of one piece each but may be of not more than two pieces, provided the joint is reinforced. The trays are to be lock-cornered and pinned top and bottom. Trays are to be painted inside and outside with at least two coats of acid-proof paint. The trays for batteries specified for medium and heavy truck service shall be provided with spacers and tie-bolts, or other construction to provide additional strength.

Handles are to be of good quality steel or other malleable metal securely attached to ends of tray. Handles are to project above the intercell connectors to protect the connectors from the top of the battery box, but the overall height is not to exceed that previously specified. Handles are to be coated with lead and then heavily coated with acid-proof paint.

Electrolyte is to be a solution of sulphuric acid in pure water of density not exceeding 1.310 at 25 deg. cent. (77 deg. fahr.) when the battery is fully charged. When specified by the War Department for use in hot climates the density of acid at 25 deg. cent. (77 deg. fahr.) shall not exceed 1.225 under the same conditions.

Tests of the Batteries

Measurements of the ampere-hour capacity of the batteries are to be made at the following rates of discharge, or more, and the results are to be expresssd as the capacity at 25 deg. cent. (77 deg. fahr.). Tests are to be made with the normal density of acid not to exceed 1.310 at 25 deg. cent. (77 deg. fahr.). The rates and the end-voltages required are as follows:

Rate of Discharge	End-Voltage per Cell
5-hr.	1.70
20-min.	1.50

The battery shall be completely charged and allowed to stand idle four weeks. The decrease in capacity at the end of this period when discharged at the 5-hr. rate shall not exceed 30 per cent. of the capacity as determined in the preceding paragraph.

For 1 hr. the battery is to be subjected to a vibration consisting of a simple harmonic motion having a frequency of 1000 vibrations per min. through a vertical displacement of 5 mm. (0.2 in.). The battery is to be discharged at approximately the 5-hr. rate. It must maintain a steady voltage and current. The cell terminals must not become loose in the covers nor the electrolyte flood the top of the battery. At the conclusion of this test the cells will be examined for broken connectors, straps and plates and for excessive sediment.

Samples of electrolyte are to be drawn with a clean pipette from the cells when fully charged. The maximum allowable impurities in the electrolyte taken from the cells are as follows:

Color	none
Suspended matter	trace
Platinum	none
Antimony and arsenic	trace
Manganese, per cent	0.005
Iron, per cent	0.012
Copper, per cent	0.005
Oxides of nitrogen	trace
Chlorides calculated as chlorine, per cent	0.012
Organic matter	trace

State of Batteries at Time of Delivery as Required

Batteries intended for immediate use or for wet storage where suitable facilities are available are to contain electrolyte and be fully formed and charged.

Batteries in the bone dry condition are to have rubber separators only or an approved equivalent. The plates are to be fully formed.

When delivered in a moist condition the wood separators are to be thoroughly wet with water. The plates and separators are to be free from acid in appreciable quantities. The vents of the individual cells are to be sealed in an approved manner. The plates are to be fully formed.

When delivered dismantled for dry storage the plates are to be fully formed and dry. Wood separators are to be kept moist with slightly acidulated water in a suitable non-metallic container with cover. The individual parts are to be complete and to conform to the various sections of these specifications.

Motorcycle Division

As a result of a series of tests, the Motorcycle Division has recommended the adoption of S. A. E. Standard steel specifications No. 1045 and 1010 in place of the chemical analyses specified in the S. A. E. Standards for Motorcycle Spokes and Nipples and Motorcycle Rims, the tests having shown that the small increase in the phosphorus content and the wider carbon range do not affect noticeably the physical properties of the finished parts.

Non-Ferrous Metals Division

The Non-Ferrous Metals Division recently held a meeting at which it was decided to recommend a revision of the specifications for non-ferrous metals printed in S. A. E. Handbook, Vol I, pages 11 to 13c, by discontinuing and adding certain specifications. The old specification numbers were retained where possible in order not to cause confusion in purchasing. The specifications have been grouped in a logical order as follows:

White Bearing Metals	Nos. 1 to 4
Bronzes	Nos. 5 to 12
Brasses	Nos. 13 to 17
Wrought Metals	Nos. 20 to 25
Aluminum Alloys	Nos. 30 to 32

The final report of the Division will be presented at the Standards Committee Meeting Jan. 11, 1921.

Tire and Rim Division

On Nov. 22 the Tire and Rim and the Truck Divisions held a joint meeting in Cleveland at which there was discussed the advisability of revising the present S. A. E. Standard for Pneumatic Tires for Passenger Cars and Motor Trucks so as to include, with the exception of the 30 x 3½ and 31 x 4-in. clincher tires, only straight-side tires having 24-in rim-seat diameters in the 31 x 3½, 32 x 4, 33 x 4½, 34 x 5, 36 x 6, 38 x 7, 40 x 8, 42 x 9 and 44 x 10-in. sizes. The possibility and desirability of obtaining interchangeability of the 6, 7 and 8-in. pneumatic tire rims was also discussed.

In addition to the members of the two Divisions, representatives of the National Automobile Chamber of Commerce attended the meeting.

Tractor Division

The Tractor Subdivision on Belt Speeds and Belt and Pulley Widths at a recent meeting recommended that

> Pulley and clutch diameters for new equipment shall not be less than 12 in. and the pulley widths shall not be less than ½ in. wider than the belt required.

The question of governors on tractors was very thoroughly discussed and the danger of operating machines with a tractor without a governor was brought out and cases cited of threshing-machine cylinders bursting owing to tractors not equipped with governors increasing speed when the load on the machine was reduced or entirely taken off. The Subdivision therefore recommended that

> Farm tractors intended for belt operation shall be equipped with a governor and shall be designed so that a suitable speed indicating device may be attached.

The Subdivision also recommended that tractor drive belts for all purposes shall have widths of 5, 6, 7, 8 and 9 in.

The question of standard belt lengths was reviewed by the Division but no definite action was taken.

RESUMPTION OF NORMALCY

THE first law of nature is self-preservation. It is manifested in its highest form as patriotism, in its lowest as sordid greed. Between these two extremes appear all forms of selfishness, many of them by no means blameworthy, others under control or not infrequently dormant, but nevertheless certain to manifest themselves when circumstances compel.

We hear that a new order of things has come to pass; that the "rights" of labor must now be respected; that the workman will hereafter have a greater share of the products of his toil; that he must share in the management of industry and have a recognized place in government and the like. To my mind the facts warrant none of these assumptions. There is no new order. Economic laws are the same as they have always been. They are as ruthless and as inexorable as are the laws of physics. Neither has human nature changed.

The individual workman cares no more for his fellow as a class than does the employer. It follows that a union must continue to succeed or it will disintegrate and disappear. The history of the last 30 years has recorded many once powerful unions, even the names of which are now almost forgotten. The Knights of Labor and The Amalgamated Associations of Iron and Steel Workers are examples.

No material permanent change in either our social order or in our industrial structure is to be anticipated. In the contest between brains and brawn, waged since the world began, brains have always won and always will. Free play for the natural forces of trade can be counted on to exercise a beneficial influence, and they should be hampered and interfered with by government restrictions as little as possible. We cannot, of course, determine from history or from any fact at hand, how long a time it will take for conditions to become normal again.—Calvert Townley, president, American Institute of Electrical Engineers.

COLLOIDAL FUEL

DURING the war the Submarine Defense Association developed the so-called colloidal fuel, a mixture of oil and pulverized coal wherein the coal is held in suspension in the oil through the presence of a peptizing agent, called by its inventors the "fixateur." The addition of 1 per cent of "fixateur" to a mixture of 60 to 70 per cent of oil and 40 to 30 per cent of coal dust forms a sort of colloid suspension which remains homogeneous for long periods. It is claimed that this product may be used for oil-fired furnaces in about the same manner as fuel oil, and that it provides, when high-grade coal is used, a fuel of even higher calorific value per unit volume than the original oil.—W. A. Hamor.

OIL INDUSTRY

IN October 115 companies with an aggregate authorized capital of $496,968,000 were organized to engage in the various branches of the oil industry, compared with 76 formed in September.—*Journal of Commerce* (New York).

AMERICA'S BIG JOB

THERE are maintained on American farms something like 25,000,000 work animals and 500,000 tractors, principally for the one job of plowing. This power is used for other purposes, but if plowing were eliminated the amount of power could be reduced by half.

The top 7 in. of soil on a single acre is estimated to weigh 2,000,000 lb. In plowing this all has to be cut into slices and turned completely over. Multiply this by 500,000,000, the approximate number of acres plowed every year, and we will gain some idea of the dirt that has to be moved.

The farmers of the United States purchase between 1,500,000 and 2,000,000 plows annually. There are still millions of acres, in Asia and other places, that are plowed with the same kind of a crooked stick used by our sylvan ancestors, but each year the area becomes smaller under the sales pressure of American plow factories.

It is stated that the plow must be designed so that the greatest friction is at the point of the share, and from the point back to the end of the moldboard the friction must gradually diminish. If there is any point where the friction increases after the furrow has glided over an easy spot it will have a tendency to buckle and the plow will not scour. The decrease in friction must be constant and progressive by easy increments.

The story is often told that when the plow designers first came in contact with the black waxy soils of Texas they tried out a number of models without success. No matter what style of moldboard they used the plows would not scour. Finally, in sheer desperation, they made up a wooden moldboard and tried first one covering and then another. At last they tried pigskin. This gave the desired results, but of course it was an impractical material. However, they learned what sort of a surface was necessary. Their task then was to reproduce as nearly as possible the same effect with some kind of metal.

The waxy lands of Texas are very difficult to handle, because they are so fine and sticky, but when they contain the right quantity of moisture a good steel-moldboard plow will turn them. When dry, however, they are so hard that sharp heavy disc plows are the only kind that can be used. Moldboard plows cannot penetrate the soil. Heavy steel discs are used all through the semi-arid country where the soils are of a heavy type.

In many other sections of the South ordinary steel moldboards with a hard-steel share are used. This kind of plow is somewhat cheaper than a hard-steel plow or even a chilled plow, and where the soil is not abrasive it gives good service. Such a plow would not scour in the black prairie soils and it would soon cut to pieces in the sharp gravelly soils in most of the Eastern States. Where the soils are particularly sharp nothing stands up so well as chilled iron.

The multitude of models and lack of standardization are trade evils in the plow business. If all farm machinery were standardized it would not be necessary for a manufacturer to have a large number of patterns; he would not be compelled to carry a great quantity of slow-moving stock; and dealers could easily keep a stock of spare parts for each of the limited number of models on their sales floors; manufacturing costs would be much cheaper, there would be less trouble about getting repairs, and implements could be sold somewhat cheaper.

Plowing will always remain the biggest single job in agriculture and the biggest single job in the world. The welfare of all the peoples of the world depends upon how well and how thoroughly this job is accomplished.—P. S. Rose in *Country Gentleman.*

AGRICULTURE

AGRICULTURE represents a permanent investment of $80,000,000,000. The value of the products of this industry for the last year amounted to $25,000,000,000.—Secretary of Agriculture Meredith.

ACTIVITIES OF THE SECTIONS

Sections Calendar

BUFFALO
Jan. 11

DAYTON
Jan. 18—Organization Meeting

DETROIT
Dec. 17

METROPOLITAN
Dec. 14—Joint meeting with Pennsylvania Section. Tour of Yacht and Engine Plant
Jan. 20—"Service," by Cyrus J. Rankin. Visit to large New York Service Station

MID-WEST
Dec. 3—F. E. Morton

MINNEAPOLIS
Dec. 1—Present Status of the Tractor Industry
Jan. 5—Future Outlook for the Tractor
Feb. 2—Fuels
March 2—Good Roads and Equipment
April 6—Tractor Service and Repair Equipment

FURTHER interest continues to be displayed in the formation of new Sections. Among the centers of automotive interest in this country, none perhaps ranks higher than Washington, not of course from a manufacturing point of view, but from a standpoint of research and coordination with the military and naval establishments together with such civil divisions of the Government as the Bureau of Standards and the Bureau of Mines. There are therefore excellent reasons for even closer touch than now exists between the Society and these various Government agencies, and the establishment of a permanent Section in Washington is one of the means for accomplishing this result. With this end in view, a committee of local members addressed a letter to all of those members of the Society in Washington and Baltimore announcing a meeting on Nov. 19 at the Cosmos Club at which it was planned to take action on the formal organization of a Washington Section. This meeting, at which the origin, growth and aims of the Society were outlined, resulted in the continuance of the temporary organization that was formed some time ago.

The Society expects to receive, as a result of this opportunity which Washington members now have of meeting on a common ground, a number of technical papers which should be of decided interest. The advantages to be derived from attendance at Section meetings should also do much to enlarge the membership of the Society in Washington.

In addition to the Washington meeting, the Boston and Detroit Sections also held their November meetings on the 19th. The meeting at Detroit was held in the Board of Commerce Auditorium. A band concert and industrial motion pictures were the special features provided. Other meetings in the last month included that of the Minneapolis Section on Nov. 3, at which the subject of Garden Tractors was discussed by S. V. Donald; one on Nov. 12 by the Mid-West Section at which Lubricating Oils was the subject; while W. H. Metcalf gave a talk before the Pennsylvania Section on Nov. 16 on the Relations between the Automotive Engineer and the Dealer and Owner. The first meeting of the Indiana Section for this season was scheduled for Nov. 20. The Metropolitan Section varied its series of technical meetings by substituting a Festival at the Hotel Astor on Nov. 17 at which dancing was one of the principal features. C. D. Hanscom spoke before the Cleveland Section on Nov. 26 on Aerodynamics.

The Metropolitan Section has invited the members of the Pennsylvania Section to attend a joint meeting at New York City on Dec. 14. Arrangements have been made to visit a large yacht and engine plant located in that city during the afternoon. The members of both Sections will attend the Motor Boat Dinner and Meeting in the evening.

CORRECT ADDRESSES OF THE MEMBERS

A FORCE is maintained in the offices of the Society at New York City whose sole duty is to keep the addresses of the members uptodate. Approximately 200 changes of addresses are received each week by this department, and these are made promptly. In numerous cases the only notification which the Society has of a change of a member's address is a letter stating that THE JOURNAL, or some other communication, was delayed in delivery or was not received at all. It is of course impossible for the office to have a correct list of addresses unless the members send in such changes promptly. Work on the 1921 membership roster has been begun and all members who are receiving mail addressed improperly are urged to send their correct address to the office.

A list of the members for which the Society has no correct address is given below. Communications sent to the last known business connection or mail address as it appears on the records have been returned to the New York office. Any one who can supply information regarding the present location of these members or offer any suggestions as to where their correct addresses can be obtained will confer a favor upon the Society by communicating with the Secretary at the New York office. It is only by the co-operation of the entire membership that a correct mailing list can be maintained and the members receive THE JOURNAL and other communications promptly.

BARKER, GEORGE R.
BONNEY, W. L.
GREEN, L. P.
HARDING, HERBERT P.
JOHNSON, A.
LEWIS, WILL I.
LUZIUS, WILLIAM CHARLES
MCMILLAN, HORATIO G.
MILLER, JAMES A.
THEISEN, ALEXANDER J.
TUCKER, GORDON E.

BRITISH COMMERCIAL AVIATION

FREIGHT valued at $1,000,000 has been transported by airplane out of the United Kingdom this year. This freight was carried in cargo planes to France, Belgium, Denmark, Spain and Holland. Planes coming into England from the Continent carried $2,000,000 worth of imports.

This last year 1325 airplanes have arrived from the Continent and landed passengers and freight in Great Britain. They included 1079 British machines, 236 French planes, 9 Belgian and 1 Swiss. The planes departing from Britain for the Continent aggregated 1455, of which 1206 were British, 341 French, 7 Belgian and 1 Swiss. In analyzing conditions, however, the Air Ministry credits the United States Air Service as being the most successful mail service on earth.

A round trip by airplane between London and Paris costs £18, while by rail and steamer it is about £8. One way costs £10 by airplane and £4 by rail and steamer. Freight by airplane is cheaper than by the old method, parcels and other small packages costing 1/3d. per lb. by airplane and from 1¾ to 4d. per lb. by the old method.—C. L. Egtvedt in *New York Times*.

PERSONAL NOTES OF THE MEMBERS

H. L. Blomstrom has accepted a position with the Cox Brass Mfg. Co., Albany, N. Y. He was formerly connected with the Pittsburgh Model Engine Co., Pittsburgh, as production manager.

Edward E. Britigan, formerly engineer with the American Die & Tool Co., Reading, Pa., has accepted the position of consulting engineer with the Arthur L. Smith Motors, Inc., Portland, Ore. He is located at the Eastern headquarters of the organization in Reading, Pa.

John A. Cerenka, who until recently was production manager of Templeton, Kenly & Co., Ltd., Chicago, has been made manager of the sales department of the John R. Mullins Auto Co., San Antonio, Tex.

L. S. Cope is no longer metallurgist for the Hoover Steel Ball Co., Ann Arbor, Mich., but has made arrangements to represent the Dannemora Steels, Inc., 17 Battery Place, New York City.

J. L. Deering has been appointed managing director of the Giant Motor Truck Co., Vancouver, B. C., Canada. He was formerly Canadian salesman for the Aultman & Taylor Machinery Co., Mansfield, Ohio, and was located at Vancouver.

R. A. DeVlieg, for the past five years associated with the Dodge Bros. Co., Detroit, has been appointed chief engineer and factory manager of the Handley-Knight Co., Kalamazoo, Mich.

Paul W. Eells has been appointed assistant professor of mechanical engineering at the Iowa State College, Ames, Iowa. He was formerly research engineer with the LeRoi Co., Milwaukee.

G. A. Ek has become affiliated with the Automotive Corporation, Toledo, Ohio, in charge of engineering. He was formerly engineer in the experimental department of the Moline Plow Co., Moline, Ill.

Fay Leone Faurote has started a technical correspondence service known as Ideas, Garden City, N. Y. He was previously manager of the educational department of the Curtiss Engineering Corporation, also of that city.

Lisle Howard Gaylord, who until recently held the position of chief draftsman of the axle process engineering division of the General Motors Corporation, Detroit, has become engineer at the Detroit office of the New Departure Mfg. Co., Bristol, Conn.

Christian Girl, recently president of the Kalamazoo Spring & Axle Co., Kalamazoo, Mich., and formerly holding the same office with the Standard Parts Co., Cleveland, has organized the C. G. Spring Co., Kalamazoo, Mich., of which he is president.

Harry E. Harris, president and consulting engineer Hubbard & Harris, Inc., has been elected president and treasurer of Hubbard, Harris & Rowell, Inc., Bridgeport, Conn., the formation of the new corporation having been authorized at a recent meeting of the stockholders of Hubbard & Harris. Ralph K. Rowell, who was formerly equipment engineer with the International Motor Co., was elected vice-president and will have charge of the designing of special equipment and grinding machines.

John A. Howlett has been appointed manager of the field service department of the Dashiell Motor Co., Chicago. He was at one time located at Camp Mormoyle, San Antonio, Tex.

Floyd B. Hubbard, who formerly was assistant chief engineer of the Buda Co., Harvey, Ill., has become chief engineer and production manager of the tractor department of the Parrett Tractor Co., Chicago Heights, Ill.

O. E. Hunt, formerly vice-president of the Mercer Motors Co., Trenton, N. J., now holds the same office with the Hare's Motors, Inc., 16 West 61st Street, New York City.

William H. Kelley has become affiliated with the Superior Utility & Supply Co., 612 East 19th Street, New York City. He was formerly service manager of the Winther Truck Co., also of New York City.

A. W. Kuebler, who was formerly general superintendent of the Stromberg Motor Devices Co., Chicago, has accepted a position as general manager with the Expert Tool & Mfg. Co., also of that city.

C. W. Lincoln has entered the employ of the Lufkin Rule Co., Saginaw, Mich., as special machine designer. He formerly held a similar position with the Carroll Engineering Co., Dayton, Ohio.

Albert G. Lindenthal, who until recently was assistant engineer in the motor testing laboratory of the Buick Motor Co., Flint, Mich., has become engineer for the General Motors Export Co., 1764 Broadway, New York City.

J. C. Linn, formerly works manager for the Teetor-Hartley Motor Corporation, Hagerstown, Ind., has accepted a position as assistant chief engineer for the Ansted Engineering Corporation, Connersville, Ind.

P. R. Mattix has joined the production force of the Steel Products Co., Cleveland.

Clair B. Owen has severed his connection with the Cadillac Motor Car Co., Detroit, where he held the position of assistant to the production manager, and has joined the engineering department of the Lincoln Motor Co., of the same city.

Raymond W. Randall has become general manager of the Toledo Automotive Products Co., Toledo, Ohio. He was previously manager of the gas engine department of the Kohler Co., Kohler, Wis.

Louis F. Renault has accepted a position as chief engineer of the American Motors Corporation, Plainfield, N. J. He was previously assistant chief engineer for the Fulton Motor Truck Co., Farmingdale, N. Y.

I. R. Robinson has left the Naval Aircraft Factory, League Island Navy Yard, Philadelphia, to accept an appointment as chief of the division of illustration in Pennsylvania Department of Labor and Industry, Harrisburg.

Edward Ropp until recently president, general manager and engineer of the Ropp Motor Co., Chicago, has been made president and chief engineer of the Marvel Motor Co., 4239 West Madison Street, Chicago.

James Ross, previously mechanical engineer for the Bryan Harvester Co., Peru, Ind., has joined the forces of the Advance-Rumely Co., LaPorte, Ind.

R. K. Schriber has been elected vice-president of the Universal Products Co., Sandusky, Ohio. He was formerly president of the H. D. Doman Co., Oshkosh, Wis., which was recently purchased by the Universal Products Co.

The item which appeared on page 484 in the November issue of THE JOURNAL stating that Harry A. Schwartz, who was previously connected with the Defiance Machine Works, had been appointed manager of research of the National Malleable Castings Co., Cleveland, was an error. It was caused by the fact that there are two members of the Society having the same name. The one about whom the item was printed was elected in 1919 and is at the present time chief engineer of the Defiance Machine Works, Defiance, Ohio. The Harry A. Schwartz who is manager of research of the National Malleable Castings Co. was recently elected as a member of the Society.

Herbert M. Smith has become connected with the Baker-Fisk-Hugill Co., Cleveland. He was previously employed by the American Six Sales Co., also of Cleveland.

Frank B. Swartwout has accepted a position as checker and layout man in the engineering department of the Cleveland Tractor Co., Cleveland.

F. C. Thompson, manager of the Detroit office of the Morse Chain Co., is now located at the new plant of the company at Eighth and Abbott streets, that city. The automobile sales and engineering offices, which were formerly located at 1003 Woodward Avenue, have been transferred to the plant.

Adrian Van Muffling, lecturer on aeronautics, College of the City of New York, has opened an office as automotive and aeronautical consulting engineer at 299 Madison Avenue, New York City.

Applicants *Qualified*

The following applicants have qualified for admission to the Society between Oct. 10 and Nov. 10, 1920. The various grades of membership are indicated by (M) Member; (A) Associate Member; (J) Junior; (Aff) Affiliate; (S M) Service Member; (F M) Foreign Member; (E S) Enrolled Student.

AKRON RUBBER MOLD & MACHINE CO., (Aff) 917 Sweitzer Avenue, *Akron, Ohio.* Representatives: Leavitt, A. H., assistant sales manager; Wilson, E., sales manager.

AMERICAN PETROLEUM INSTITUTE (Aff) 15 West Forty-fourth Street, *New York City.* Representative: Welch, R. L., general secretary and counsel.

ASHLEY, E. G. (A) manager, Hall & Pickles, Ltd., 64 Port May Street, *Manchester, England.*

BABCOCK, WALTER F. (J) assistant chief draftsman, Foote-Burt Co., *Cleveland,* (mail) 12101 Philips Avenue, Northeast.

BAENDER, FRED G. (M) professor of heat power engineering, State University of Arkansas, *Fayetteville, Ark.*

BAKER, DAVID B. (M) assistant chief engineer, tractor department International Harvester Co., *Chicago,* (mail) 2326 South Millard Avenue.

BAYSTON, JOHN R. (J) head of automobile engineering department, American School of Correspondence, *Chicago,* (mail) 1960 Sunnyside Avenue.

BLACK, DONALD R. (M) engineer, A. & D. R. Black, Evening Star Building, *Washington.*

BLAKE, H. FRASER (A) sales engineer, Doehler Die-Casting Co., Brooklyn, N. Y., (mail) 880 West 181st Street, *New York City.*

BLOOM, EDGAR J. (A) manufacturer, Bloom Flusher Co., *Tiffin, Ohio.*

BORGERD, W. F. (M) assistant chief engineer of stationary engines, tractor works, International Harvester Co., 2600 West 31st Boulevard, *Chicago.*

BRADY, ARTHUR C. (J) designing engineer, Curtiss Engineering Corporation, Garden City, N. Y., (mail) 50 West End Avenue, *Manhattan Beach, N. Y.*

BRIMBLE, GEORGE D. (M) assistant chief draftsman, Transport Truck Co., *Mount Pleasant, Mich.*

BROKAW, CLIFFORD (M) director technical schools, West Side Y. M. C. A., *New York City,* (mail) 68 West 162nd Street.

BURGER, L. F. (M) chief engineer of stationary engines, tractor works, International Harvester Co., Chicago, (mail) Herrick Road, *Riverside, Ill.*

BUTLER, ARTHUR G. (J) layout draftsman, Curtiss Aeroplane & Motor Corporation, Garden City, N. Y., (mail) 234 River Avenue, *Patchogue, N. Y.*

CASSERKY, GRAHAM (A) assistant to research engineer, Hare's Motors, Inc., *Bridgeport, Conn.,* (mail) 554 Carrol Avenue.

CHIEVITZ, WILLIAM J. (M) experimental engineer, Cleveland Automobile Co., Euclid Avenue and London Road, *Cleveland.*

CHOATE, F. P. (A) department manager, Sears, Roebuck & Co., *Chicago.*

CORCORAN, LOU A. (A) manager, stamping division, Zenite Metal Co., 201 North West Street, *Indianapolis.*

CRAWFORD, JAMES M. (M) chief engineer, Allen Motor Co., 400 Dublin Avenue, *Columbus, Ohio.*

CRUICKSHANK, JAMES A. (M) chief engineer, Interstate Foundry Co., 5939 West 66th Street, *Chicago.*

DENVER ROCK DRILL MFG. CO. (Aff) 39th and Williams Streets, *Denver, Col.* Representative: Skaer, A. H., vice-president and works manager.

DIMEO, JAMES J. (A) general superintendent, Jaxon Co., 1014 Jackson Street, *Toledo, Ohio.*

DRESSER, DANIEL L. R. (J) service manager, Dechert & Walkers Motors Co., 288 Belmont Avenue, *Springfield, Mass.*

ELCONIN, E. V. (M) chief engineer, Eaton Axle Co., *Cleveland.*

EVES A. P. (M) chief chemist and metallurgist, International Harvester Co., *Chicago,* (mail) 6224 Eberhart Avenue.

FLYNN, F. K. (A) chief engineer, Luce Sugar Cane Harvester Co., *Watertown, Wis.,* (mail) 1 Main Street.

FRY, H. DELONG (A) importer and exporter, H. DeLong Fry & Co., 20 Broad Street, *New York City.*

GALLIVAN, JOHN M. (E S) student, Syracuse University, Syracuse, (mail) 213 West Hickory Street, *Canastota, N. Y.*

GARDNER, GILBERT M. (M) consulting representative, engineering division, Air Service, c/o Wittemann & Lewis Aircraft Corporation, *Hasbrouck Heights, N. J.*

GRIFFITH, R. R. (M) instructor, University of Minnesota, Mechanical Engineering Building, *Minneapolis.*

HAGGART, J. C., JR. (M) assistant chief engineer, Republic Motor Truck Co., Inc., *Alma, Mich.*

HEATH, LEE M. (J) draftsman, Chevrolet Motor Co., Long Island City, N. Y., (mail) 202 Ridgewood Avenue, *Brooklyn, N. Y.*

HEBBELN, LOUIS (J) draftsman, O. E. Szekely Co., *Moline, Ill.,* (mail) 2006 Marquette Street.

HEINISH, GEORGE (J) draftsman, Paragon Motor Car Co., *Cleveland,* (mail) 3220 West 61st Street.

HERMAN, ISER (J) aeronautical draftsman, Massachusetts Institute of Technology, *Cambridge, Mass.*

HERTZLER, ARTHUR G. (A) sales and purchase manager, Bearings Co. of America, *Lancaster, Pa.*

HOLCOMB, WALTER W. (A) garage manager, Fisk Rubber Co., Chicopee Falls, Mass., (mail) 55 Northampton Avenue, *Springfield, Mass.*

HOLSTEAD, JOHN W. (M) mechanical engineer, E. W. Bliss Co., *Brooklyn, N. Y.,* (mail) 244 Sixth Avenue.

HOWATT, GERALD (M) national service manager, Willard Storage Battery Co., *Cleveland,* (mail) 3203 Whitethorn Road.

HUTCHINSON, THOMAS MASSIE (F M) chief inspector of motor transportation, British Army, London, (mail) 57 Alexandra Road, *Wimbledon, England.*

JACOBI, EDWARD (M) chief engineer, Briggs & Stratton Co., Milwaukee, Wis., (mail) 204 25th Street.

KEAGY, A. REUEL (J) assistant sales engineer, Republic Motor Truck Co., Inc., *Alma, Mich.,* (mail) 531 State Street.

KILBOURNE & JACOBS MFG. CO. (Aff) Lincoln and Fourth Streets, *Columbus, Ohio.* Representatives: Hileman, H. B., assistant general manager; VandeWater, S. R., consulting engineer.

KINDL, CARL H. (M) designing engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa., (mail) 511 Sheridan Avenue, *Pittsburgh.*

KOELLNER, LOUIE F. (J) draftsman, Fulton Iron Works, *St. Louis, Mo.,* (mail) 4514 Lewis Place.

KOGER, ESTEN B. (A) experimental pilot, bureau of engineering, Navy Department, Navy Building, *Washington.*

LANDRUM, MARK, JR. (J) instructor in manual arts, Sutter Creek Union High School, Sutter Creek, Cal., (mail) 425 East Hazelton Avenue, *Stockton, Cal.*

LEACH, HARRY G. (J) engineer, Electrical Industries Mfg. Co., 326 West 41st Street, *New York City.*

LIBBEY, JAMES T. (A) sales engineer, Doehler Die-Casting Co., Brooklyn, N. Y., (mail) 48 Garfield Building, *Detroit.*

LORING, ERNEST J. (M) mechanical engineer, aircraft armament division, Ordnance Department, Frankford Arsenal, Philadelphia, (mail) 1033 Herbert Street, *Frankford, Pa.*

McLAUGHLIN, WILSON (M) engineer, Muskegon Motor Specialties Co., North Terrace Street, *Muskegon, Mich.*

MACDONALD, HOWARD D. (M) assistant manager, gas power engineering, International Harvester Co., 606 South Michigan Avenue, *Chicago.*

MADDEN, E. B. (M) chief engineer and factory manager, Comet Automobile Co., *Decatur, Ill.,* (mail) 268 Stewart Avenue.

MERRILL, ALDEN (M) technical supervisor, American Brass Co., 446 Military Road, *Buffalo, N. Y.*

MORRIS, A. C. (J) designer, Simplex Short Turn Trailer Co., *Lugro, Ind.*

NEELY, E. HAROLD (M) sales engineer, Standard Steel & Bearings Co., Philadelphia, (mail) 646 North Meridian Street, *Indianapolis, Ind.*

NEUTEBOOM, B. B. (M) consulting engineer, Taylor & Neuteboom, 1540 David Whitney Building, *Detroit, Mich.*

OVERSMITH, RALPH E. (J) chief engineer, Buffalo Truck & Tractor Corporation, 37 Carolina Street, *Buffalo.*

O'NEAL, E. P. (J) instructor, Okmulgee Vocational High School, *Okmulgee, Okla.*

PAGE, EMMETT L. (M) assistant production manager, Oakland Motor Car Co., *Pontiac, Mich.,* (mail) 73 Henry Clay Avenue.

PALMER, RALPH B. (M) engineer, J. W. Murray Mfg. Co., Clay and St. Alburn Avenues, *Detroit,* (mail) 184 King Avenue.

PALMGREN, CHARLES A. (M) manager of works, Pittsburgh Model Engine Co., *Pittsburgh,* (mail) P. O. Box 958.

PARKHILL, GEORGE B. (M) engineer, All-American Truck Co., Chicago, (mail) 305 High Street, *Mount Pleasant, Mich.*

PARTRIDGE, A. G. (A) vice-president, Firestone Tire & Rubber Co., *Akron, Ohio.*

PFAUSER, EDWARD M. (J) chief engineer, Texas Motor Car Association, *Fort Worth, Tex.,* (mail) 504 Lipscomb Street.

PFEIFFER, CLARENCE (J) body engineer, William Pfeiffer Auto & Carriage Works, *Omaha, Neb.,* (mail) 1121 Park Avenue.

PIERCE, GEORGE W. (A) manufacturer, Pierce Governor Co., *Anderson, Ind.*

PICKETT, E. V. (A) sales engineer, Bissinger Co., *Cleveland,* (mail) 2298 Bellfield Avenue.

PUTNAM, W. P. (M) president and general manager, Detroit Testing Laboratory, 674 Woodward Avenue, *Detroit.*

QUETSCH, L. J. (M) manager, engineering department, A. M. Castle & Co., 715 North Morgan Street, *Chicago.*

REEPMAKER d'ORVILLE, THEODORE L. (M) research development engineer, Standard Steel Spring Co., Coraopolis, Pa., (mail) P. O. Box 88, *Sewickley, Pa.*

REISSER, HARRY (A) sales engineer, Link-Belt Co., *Indianapolis.*

ROBERTS, EUGENE D. (M) vice-president and general manager, Puget Sound Iron & Steel Works, Canal Street, *Tacoma, Wash.*

ROSSMASSLER, CARL (M) instructor in charge of machine design, Cooper Union, New York City (mail) 124 State Street, *Brooklyn, N. Y.*

ROTERT, HARRY E. (A) sales inspection engineer, Timken-Detroit Axle Co., Detroit, (mail) 1403 Conway Building, *Chicago.*

ROUSE, W. BRYAN (A) chief engineer, Lack Mfg. Co., Paducah, Ky., (mail) *Avondalle Heights, Ky.*

SAYLOR, PARRY D. (A) vice-president and general manager, Dunlop Tire & Rubber Corporation of America, *Buffalo, N. Y.,* (mail) P. O. Box 448.

SCHLACHTER, DEAN H. (A) supervisor motor mechanics school, Fort Crook, Neb., (mail) 2333 South 35th Avenue, *Omaha.*

SCHNEIDER, WILLIAM G. (J) electrical engineer, Maxwell Motor Co., *Detroit*, (mail) 140 Calvert Avenue.

SELLS, OSBORNE P. (M) Eastern district engineer, Double Seal Ring Co., Chicago, (mail) 1834 Broadway, *New York City*.

SLATER, R. J. (J) experimental engineer, Chandler Motor Car Co., *Cleveland*, (mail) 472 East 124th Street.

SLOYAN, JEROME J. (J) service engineer, General Ordnance Co., *New York City*, (mail) 28 East Kingsbridge Road.

SMITH, CHARLES H. (A) sales manager and sales engineer, Allegheny Gear Works, *Pittsburgh, Pa.*

SPERRY, LEONARD BOYD (M) chief engineer of tractors, International Harvester Co., Chicago, (mail) P. O. Box 587, *Riverside, Ill.*

STARR, C. F. (A) general manager, Perfecto Gear Differential Co., King and North Streets, *Bellingham, Wash.*

STEVENS, WILLIAM CLIFFORD (A) sales manager, Cutler-Hammer Mfg. Co., *Milwaukee, Wis.*, (mail) P. O. Box 1564.

STROM, HERBERT A. (M) chief engineer, truck axle division, Eaton Axle Co., Cleveland, (mail) 14419 Alder Avenue, *East Cleveland, Ohio.*

THOMAS, BEN (M) engineer magnetic shift department, Cutler-Hammer Mfg. Co., *Milwaukee, Wis.*, (mail) 3012 Chestnut Street.

THOMPSON, BURT D. (A) sales engineer, Charles A. Strelinger Co., 149 East Larned Street, *Detroit.*

THROCKMORTON, GEORGE K. (A) manager, isolated plant department, Sears, Roebuck & Co., *Chicago*, (mail) 3916 Jackson Boulevard.

TOLMAN, EDGAR B., JR. (M) president, Tolman-Reeve Engineering Corporation, 3104 Michigan Avenue, *Chicago.*

TREVOR, KARL ROBERT (M) laboratory engineer, H. H. Franklin Mfg. Co., *Syracuse, N. Y.*, (mail) 438 Columbus Avenue.

WATTS, W. A. (M) chief of experimental department, Massey Harris Co., King Street, West, *Toronto, Ont., Can.*

WELLS, MILTON HOWARD (M) assistant to president, director of purchasing and chief engineer, W. H. Allison Co., *Detroit*, (mail) 37 Canfield Avenue, East.

WERTHEIM, CHARLES (A) sales engineer, Doehler Die-Casting Co., *Brooklyn, N. Y.*, (mail) 1522 New York Avenue.

WHITNEY, MAURICE P. (J) development engineer, Eclipse Machine Co., Elmira, N. Y., (mail) 128 West 12th Street, *Elmira Heights, N. Y.*

WILLS, JOHN H. (A) president and general manager, John H. Wills Sales Co., Inc., 360 Belleville Avenue, *Newark, N. J.*

WOODS, WILLIAM H. (J) draftsman, Service Motor Truck Co., *Wabash, Ind.*

WRIGHT, BERNARD F. (M) chief engineer, Republic Motor Truck Co., Inc., *Alma, Mich.*, (mail) 424 Park Avenue.

YOUNG, FREDERICK C. (J) assistant chief chemist, Ford Motor Co., Highland Park, Mich., (mail) 870 Concord Avenue, *Detroit.*

ZIMMERMAN, OLIVER BRUNNER (M) engineer, experimental department, International Harvester Co., 606 Michigan Avenue, *Chicago.*

ZUMMACH, JOHN G. (M) chief engineer and assistant factory manager, Perfex Radiator Co., *Racine, Wis.*, (mail) 1620 Holmes Avenue.

Applicants *for* Membership

The applications for membership received between Oct. 16 and Nov. 19, 1920, are given below. The members of the Society are urged to send any pertinent information with regard to those listed which the Council should have for consideration prior to their election. It is requested that such communications from members be sent promptly.

AMADON, CHARLES S., broach designer, *New London, Conn.*

APPLEBY, FRED., designer, Holt Mfg. Co., *Peoria, Ill.*

ARMSTRONG, V. M., assistant purchasing agent, Stutz Motor Car Co., *Indianapolis, Ind.*

AUCOCK, HERBERT, Herbert Aucock Co., *Boston.*

AUDE, JOHN R., shop and service manager, Maxwell-Chalmers Co., *Brooklyn, N. Y.*

BAILEY, CHARLES E., sales and advertising manager, Paragon Motor Car Co., *Connellsville, Pa.*

BARBOUR, EDWARD L., charge of production contracts, International Nickel Co., *New York City.*

BARNARD, GEORGE A., 2ND, acting automobile engineer, Graton & Knight Mfg. Co., *Worcester, Mass.*

BARTUSKA, JOHN F., engineer, Maremont Mfg. Co., *Chicago.*

BASKERVILLE, DEAN E., body engineer, Dodge Bros., *Detroit.*

BECHTLOFFT, CLAUDE B., experimental engineer, Bijur Motor Appliance Co., *Hoboken, N. J.*

BELL, JAMES A., secretary and general manager, Menominee Motor Truck Co. of Wisconsin, *Clintonville, Wis.*

BENNINGHOFF, WILLIAM E., time study engineering, Western Automatic Machine Screw Co., *Elyria, Ohio.*

BLAKE, ORMOND L., president and general manager, Blake Engineering Corporation, *Detroit.*

BICKNELL, G. M., chief engineer, Carter Carbureter Co., *St. Louis.*

BRERETON, FREDERICK R., checker and assistant to chief draftsman, Splitdorf Electrical Co., *Newark, N. J.*

CHILSON, CLARENCE E., manager, Chilson Oil Co., *Fargo, N. D.*

CLARK, REGINALD, assistant superintendent, J. H. Williams & Co., *Buffalo.*

CLEAVER, BENJAMIN J., experimental engineer, Briscoe Devices Co., *Pontiac, Mich.*

COLEMAN, CHARLES T., powerplant section, Bureau of Standards, *Washington.*

COLSTAD, CHARLES N., chief engineer, National Chain Motor Service Corporation, *Boston.*

DE SMET, EDGARD C., assistant chief engineer, Pan Motor Co., *St. Cloud, Minn.*

DE VIGNIER, ROBERT MOTT, chief engineer, American Vulcanized Fibre Co., *Wilmington, Del.*

DICKSEE, CEDRIC BERNARD, Westinghouse Electric & Mfg. Co., *East Pittsburgh, Pa.*

DUGGAN, T. O., Pacific Coast representative, Chanslor & Lyon Co., *San Francisco.*

EBERLE, J. P., stockkeeper and service worker, Blocker & Bourlind, *Fort Smith, Ark.*

ELLER, ULYSSES GRANT, JR., draftsman, Dodge Bros., *Detroit.*

FAHNESTOCK, MURRAY, technical editor, Trade Press Publishing Co., *Milwaukee.*

FEILER, ALLEN, designer, Splitdorf Electrical Co., *Newark, N. J.*

FENNER, PAUL R., manager of manufacturing, R-S Mfg. Co., *Kansas City, Mo.*

FRIEL, LESTER D., tractor designer, Emerson-Brantingham Co., *Minneapolis.*

FREEMAN, GEORGE W., mechanical supervisor, Buick Motor Co., *New York City.*

GOTTLIEB, MARSHALL D., mechanical engineer, Single Sleeve Motors, Inc., *Chicago.*

HANNA, W. H. MARK, sales engineer, Bethlehem Spark Plug Co., Inc., *Bethlehem, Pa.*

HAVENS, SAMUEL M., assistant treasurer and works manager, Ingalls-Shepard division, Wyman-Gordon Co., *Harvey, Ill.*

HARRIMAN, DANIEL F., chief engineer, Scientific Automotive Corporation, *Hoboken, N. J.*

HECHT, ALEXANDER S., general manager, Guaranteed Magneto Parts Co., *New York City.*

HEYMANN, BRUNO, dean and head of engineering department, California School of Mechanical Arts, *San Francisco.*

HIGLEY, FRANK R., student, law school of Harvard University, *Cambridge, Mass.*

HOURWICH ISKANDER, aeronautical mechanical engineer, engineering division, Air Service, *Dayton, Ohio.*

HUMMER, CHARLES J., chief engineer, Vreeland Motor Co., Inc., *Newark, N. J.*

JONES, ABNER C., metallurgical engineer, Electric Steel Co., *Chicago.*

JONES, RICHARD L., president, Auto Leather Mfg. Co., Inc., *Arlington, N. J.*

JONTZ, G. F., chief inspector, tractor works, Moline Plow Co., *Rock Island, Ill.*

KEEL, CHARLES H., patent attorney, Curtiss Aeroplane & Motor Corporation, *Garden City, N. Y.*

KING, LESLIE E., solid and pneumatic tire designer, Kuhlke Machine Co., *Akron, Ohio.*

KROYER, J. M., manufacturer, Kroyer Motors Co., *Stockton, Cal.*

LAMBERT, G. F., chief engineer, Kroyer Motors Co., *Stockton, Cal.*

LEET, ALBERT B., chief draftsman, Rockford Drilling Machine Co., *Rockford, Ill.*

LEFEVRE, C. D., Sections Secretary, Society of Automotive Engineers, *New York City.*

LINTING, G. T., chief tool engineer, Stutz Motor Car Co. of America, Inc., *Indianapolis.*

LUDWICK, H. V., chief engineer, Budd Wheel Corporation, *Philadelphia.*

LUX, G. J., chief engineer, Detroit Gear & Machine Co., *Detroit.*

MCDONALD, HARRY T., designer, Holt Mfg. Co., *Peoria, Ill.*

MCGRAW, E. J., production supervisor, Kelly-Springfield Motor Truck, Co., *Springfield, Ohio.*

MAY, C. N., master engineer, Empire Welding Co., *Croyden, England.*

MIDGLEY, A. H., chief engineer and adviser, C. A. Vanderwell & Co., Ltd., *London, England.*

MILLER, G. REYNOLDS, general purchasing agent, Daniels Motor Co., *Reading, Pa.*

MINER, ROBERT I., sales engineer, Bossert Corporation of Utica, *Utica, N. Y.*

MURPHY, EUGENE ALLSTON, purchasing engineer, Denby Motor Truck Co., *Detroit.*

MURPHY, THOMAS A., traveling representative, Universal Battery Co., *Chicago.*

MURRAY, JOSEPH J., general manager, P. A. Murray & Co., *Newton, Mass.*

NANSEN, W. D., draftsman, Moon Motor Car Co., *St. Louis.*

NELSON, HENRY C., vice-president and general manager, Mullins Body Corporation, *Salem, Ohio.*

NEWMAN, ARTHUR B., tractor designer, Holt Mfg. Co., *Peoria, Ill.*

NEWTON, M. H., advertising manager, White Co., *Cleveland.*

NICHOLSON, DONALD J., test engineer, International Harvester Co., *Chicago.*

NIHLEAN, F. R., draftsman, Stromberg Motor Devices Co., *Chicago.*

NYDEN, CLARENCE A., experimental designer, Mitchell Motors, Inc., *Racine, Wis.*

OKSNEVAD, PETER, assistant chief engineer, Rees Motor Co., *Columbus, Ohio.*

OSTERHELD, CLARK M., chief engineer, Stoughton Wagon Co., *Stoughton, Wis.*

OVERMAN, PHIL. N., sales engineer, Hyatt Roller Bearing Co., *Chicago.*

PATTERSON, ARTHUR E., assistant to Chester S. Ricker, automotive engineer, *Indianapolis.*

PEDERSEN, ANDREW L., president and general manager, Adapt Machinery Co., *Chicago.*

PIKE, WALTER LEE, assistant engineer, Aero Products Co., *Cleveland.*

REDFIELD, C. S., manager, development department, Dunlop Tire & Rubber Corporation of America, *Buffalo.*

ROBIE, THEODORE M., mechanical engineer, Fairbanks, Morse & Co., *Beloit, Wis.*

ROBBINS, ROY MONROE, mechanical and automotive draftsman, Comet Automobile Co., *Decatur, Ill.*

ROCKWELL, STANLEY PICKETT, metallurgist, Whitney Mfg. Co., *Hartford, Conn.*

ROGERS, DUDLEY T., sales engineer, American Bosch Magneto Corporation, *Springfield, Mass.*

ROLLER, WILLIAM F. C., draftsman, William E. Quimby, Inc., *Newark, N. J.*

RUPPERT, GEORGE H., engineering department, General Tire & Rubber Co., *Akron, Ohio.*

SCOBIE, VERNON, lecturer and instructor, West Side Y. M. C. A. Automobile School, *New York City.*

SELENSKY, FLOYD B., draftsman, Waterloo Gasoline Engine Co., *Waterloo, Iowa.*

SHEELINE, PAUL D., commercial engineer, A. D. Little, Inc., *Cambridge, Mass.*

SHORT, FRANK, expert, Ordnance Department, Frankford Arsenal, *Philadelphia.*

SILVERMAN, JESSE, manager of technical department, Syracuse Motor Car Co., *Syracuse, N. Y.*

SNYDER, FLOYD E., chief inspector, Stutz Motor Car Co., *Indianapolis.*

STEVENS, R. L., instructor on automotive electrical equipment, United Motors Service, *Detroit.*

STEWART, GEORGE C., chief engineer, Stewart Tractor Co. of Wisconsin, *Waupaca, Wis.*

STRADER, M. E., draftsman, Fairbanks, Morse & Co., *Beloit, Wis.*

STROM, G. A., motor truck designer, Erie Motor Truck Mfg. Co., *Erie, Pa.*

SYFAN, ROLLINS C., assistant secretary, Stroud Motor Mfg. Association, *San Antonio, Tex.*

TANAKA, CAPT. TATSUZO, I. J. N., *Kure Naval Arsenal, Japan.*

TAYLOR, PAUL B., engineer, Oakland Motor Car Co., *Pontiac, Mich.*

TISHLER, FRANK J., assistant engineer, Cleveland Motorcycle Mfg. Co., *Cleveland.*

WALTON, GEORGE, production manager, Self-Seating Valve Co., *Chicago.*

WARNER, CAPT. WALTER W., coast artillery school, U. S. Army, *Fortress Monroe, Va.*

WARSHAW, NATHANIEL, chief engineer, Murray & Tregurtha Corporation, *Quincy, Mass.*

WATKIN, LEWIS M., JR., Eastern sales manager, Standard Steel & Bearings, Inc., *Philadelphia.*

WEINBERG, SAMUEL R., automobile expert, Standard Auto & Ignition Repair Shop, *Brooklyn, N. Y.*

WELCH, AUSTIN HORACE, assistant manager, Massachusetts Oilless Bearings Co., *Worcester, Mass.*

WELLS, DONALD W., vice-president and general manager, Electric Steel & Forge Co., *Cleveland.*

WEYL, PIERCE A., mechanical engineer, Anderson Foundry & Machine Co., *Anderson, Ind.*

WILLSHAW, HARRY, assistant factory manager, Dunlop Tire & Rubber Co. of America, *Buffalo.*

WILSON, HERBERT L., draftsman-in-charge of aeronautical design, bureau of engineering, Navy Department, *Washington.*

WOLFINGER, LOUIS F., service engineer, J. F. Dixon Co., *Los Angeles, Cal.*

WORDEN, LYLE D., Dayton Automotive Wheel Co., *Dayton, Ohio.*

YOUNG, JACK WALLACE, production engineer, New Era Spring & Specialty Co., *Grand Rapids, Mich.*

ZIMMER, R. R., chief engineer, Du Pont Motors, Inc., *Wilmington, Del.*

THE JOURNAL OF THE SOCIETY OF AUTOMOTIVE ENGINEERS

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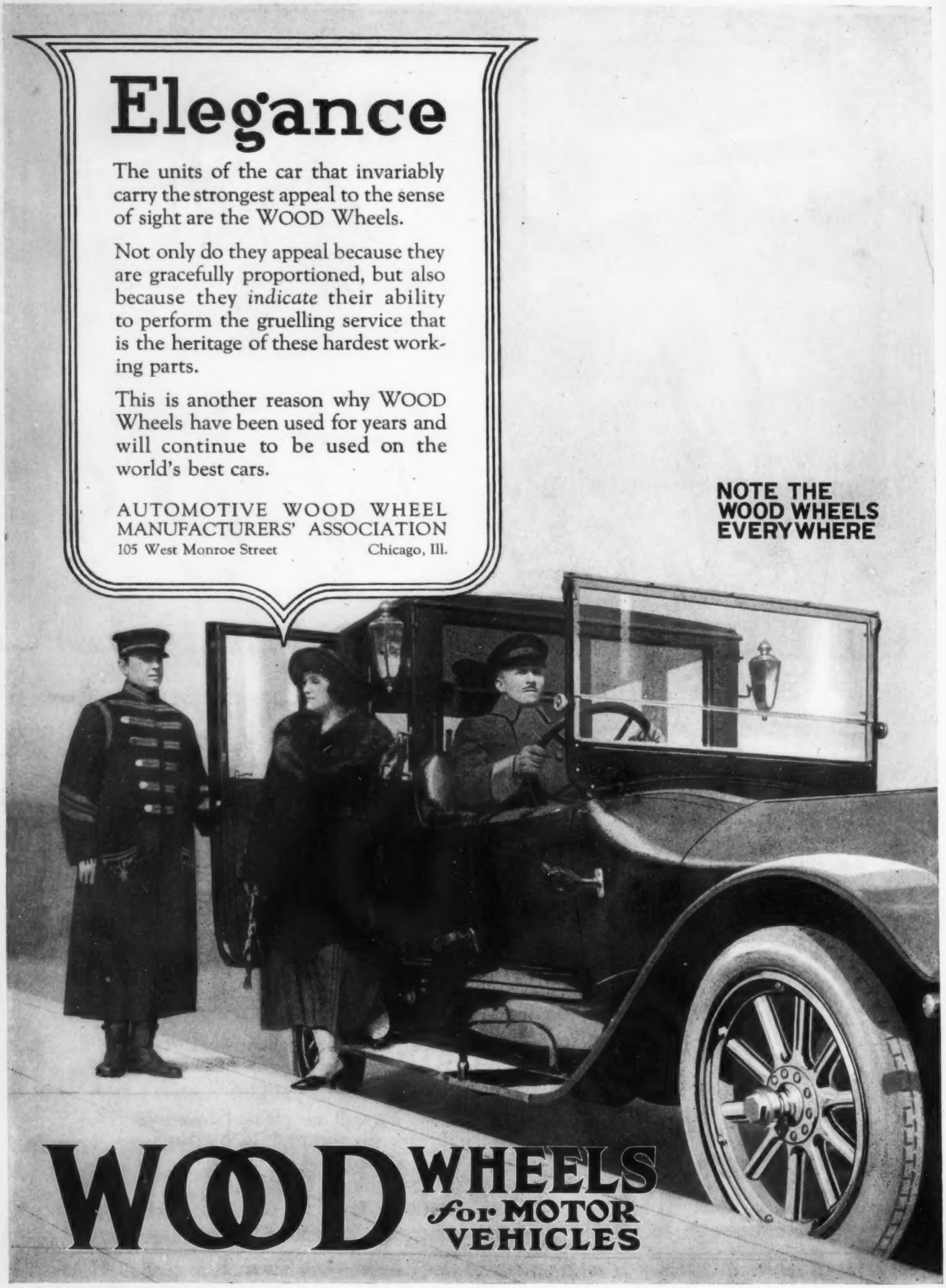
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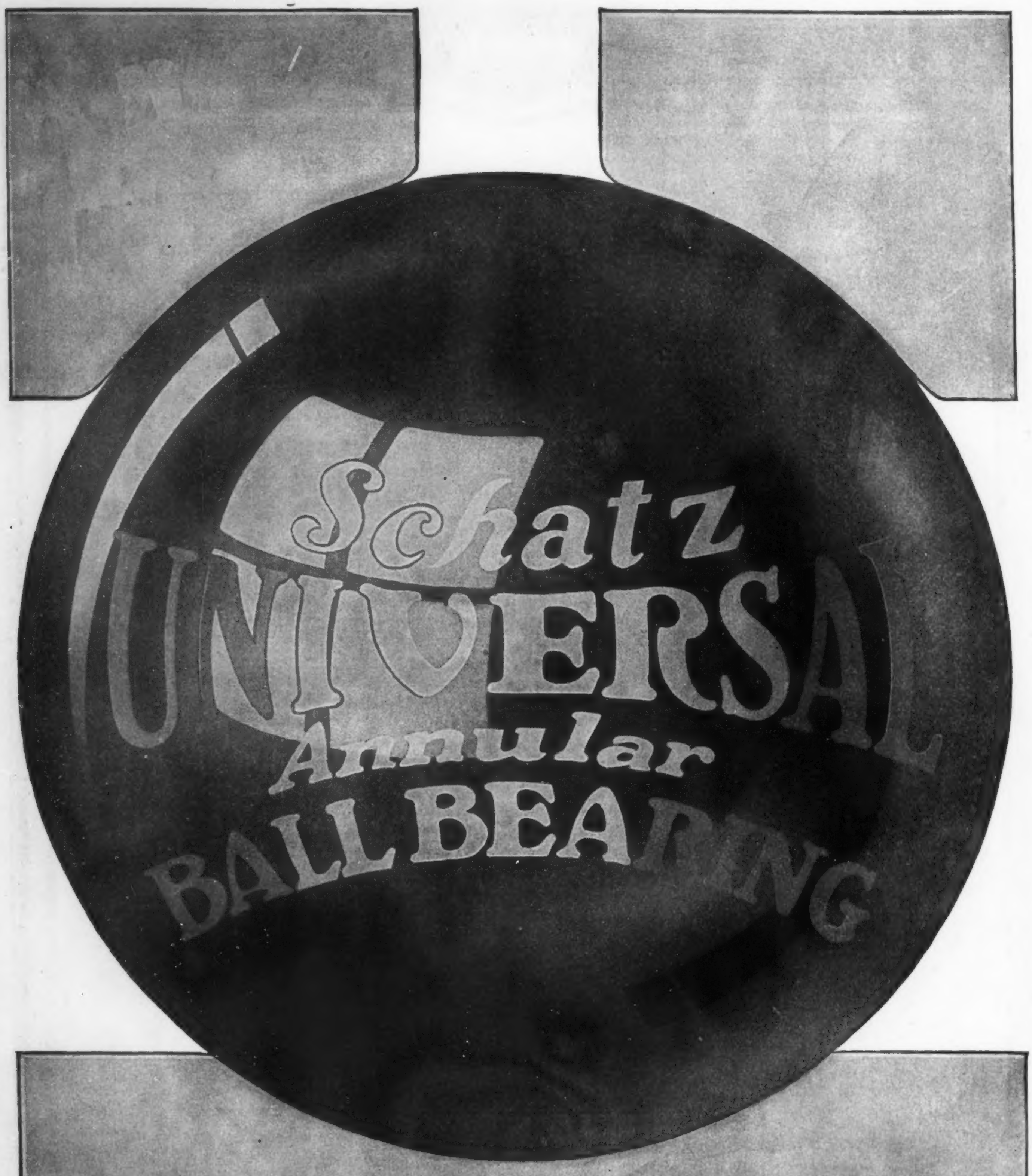
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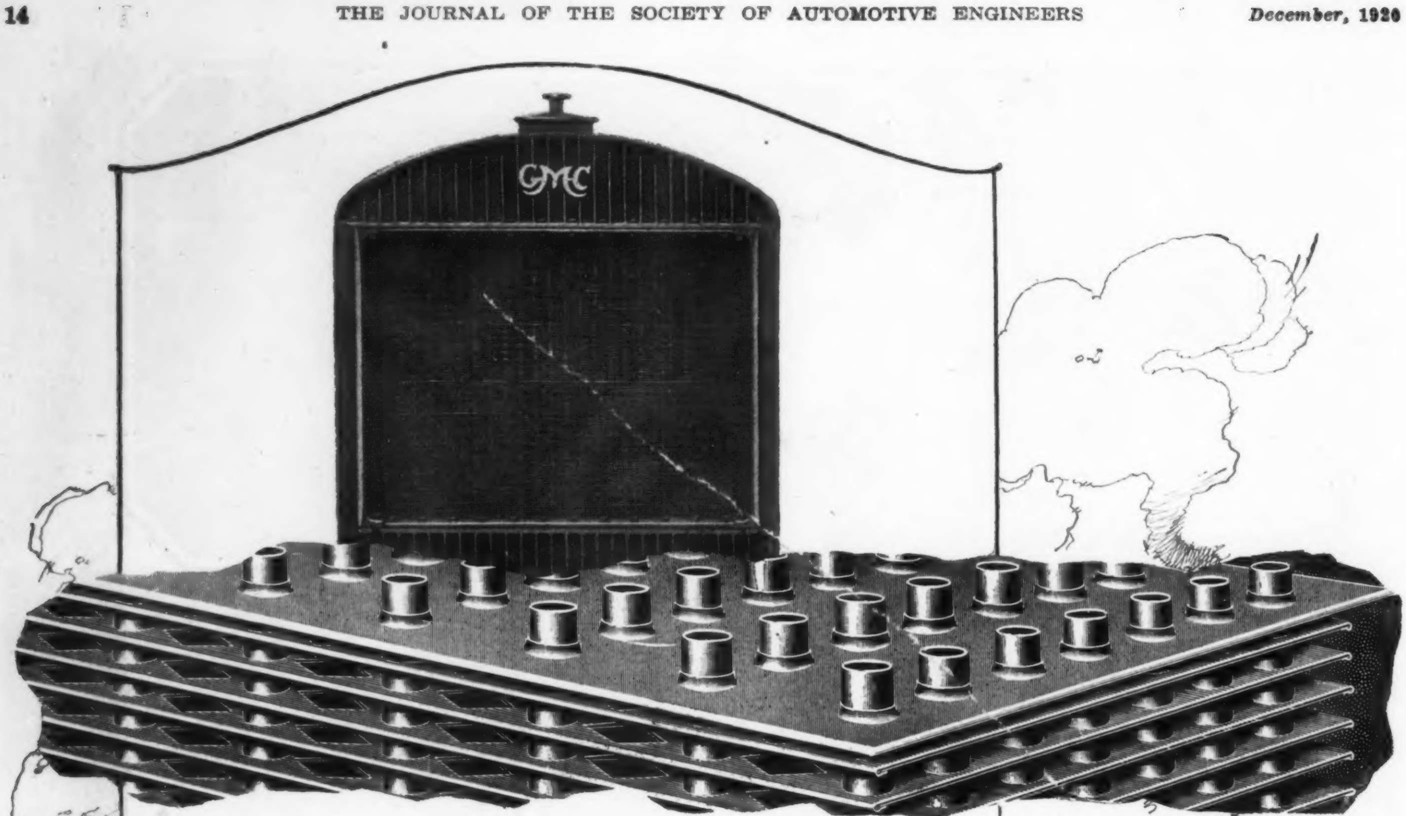

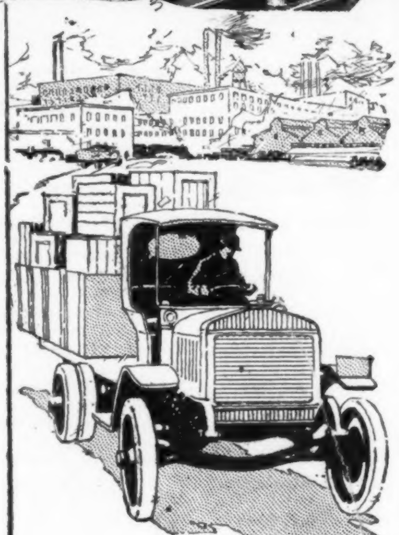

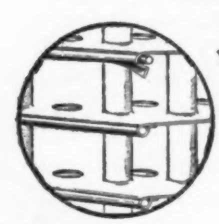

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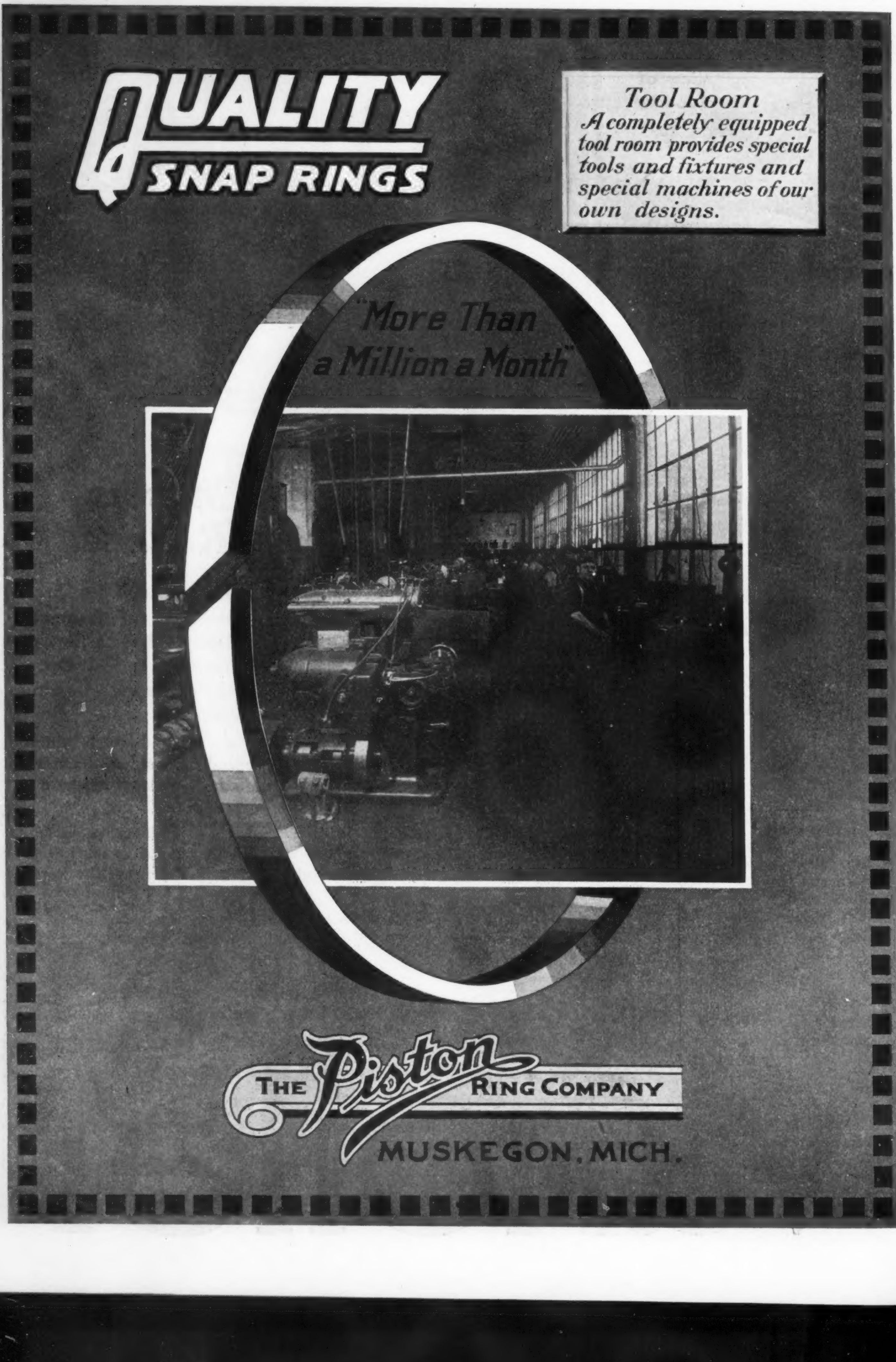
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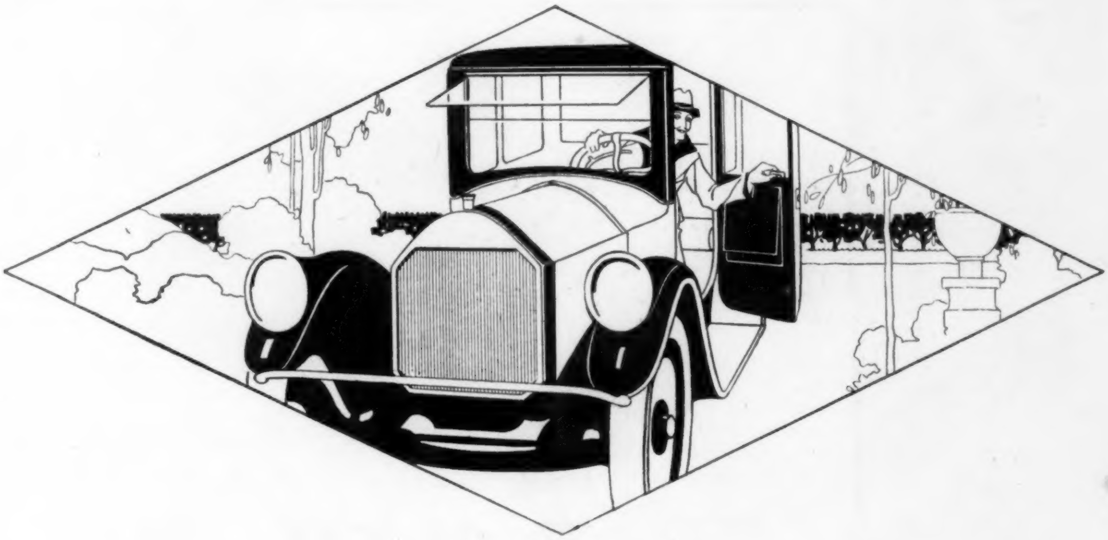

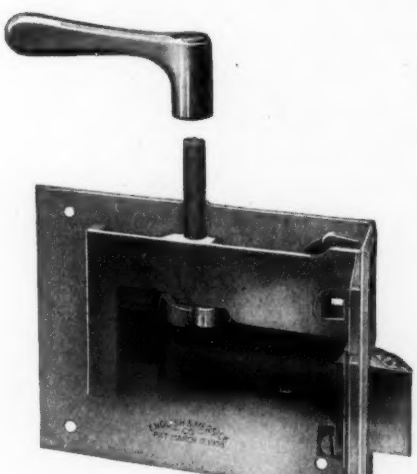


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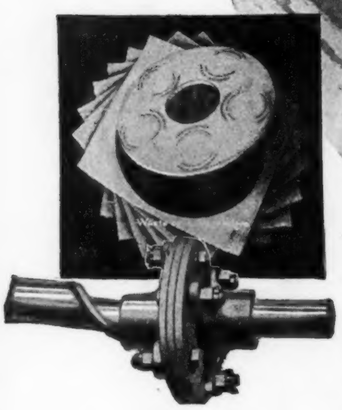

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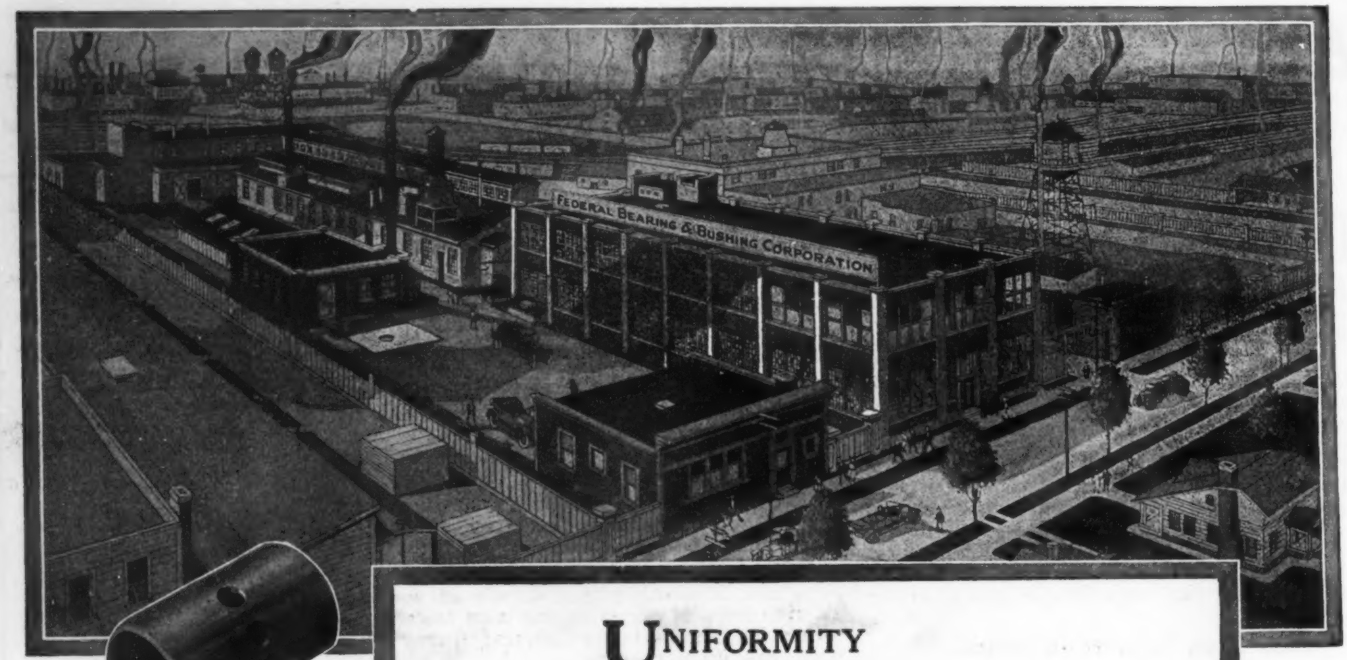
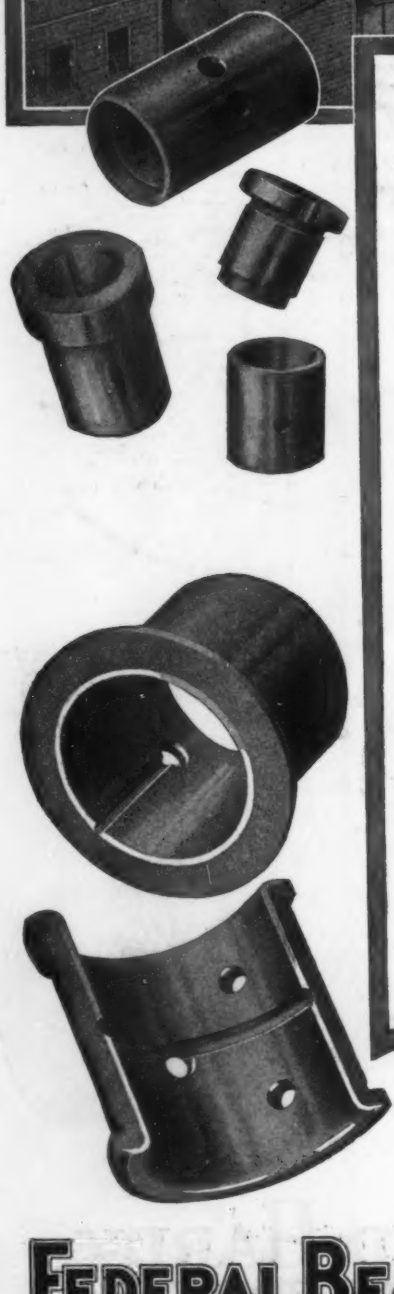
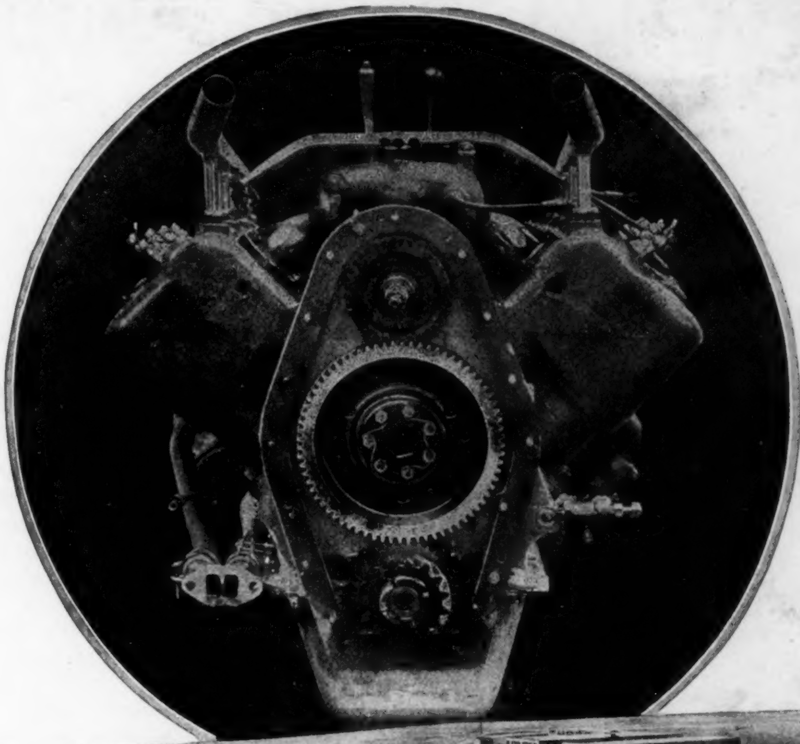
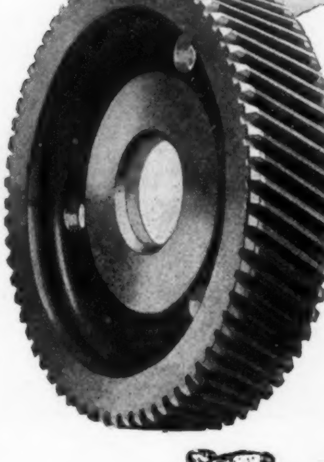

FEDERAL BEARING & BUSHING CORPORATION





Peerless



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With Peerless, as with many other makes of first-class automobile engines, Fabroil Gears are being used as the main timing gear. Because of the successful operation of Fabroils, helical gearing on front ends has made considerable gain within the last two years.

Have you ever tried one of these raw cotton gears? If you haven't you have a surprise in store for you.

Fabroils are made in all shapes and sizes—have been furnished from one to thirty inches in diameter.

Send for booklet 48703 A.

FABROIL GEARS

General Electric Company

General Office
Schenectady, N.Y.

Sales Offices in
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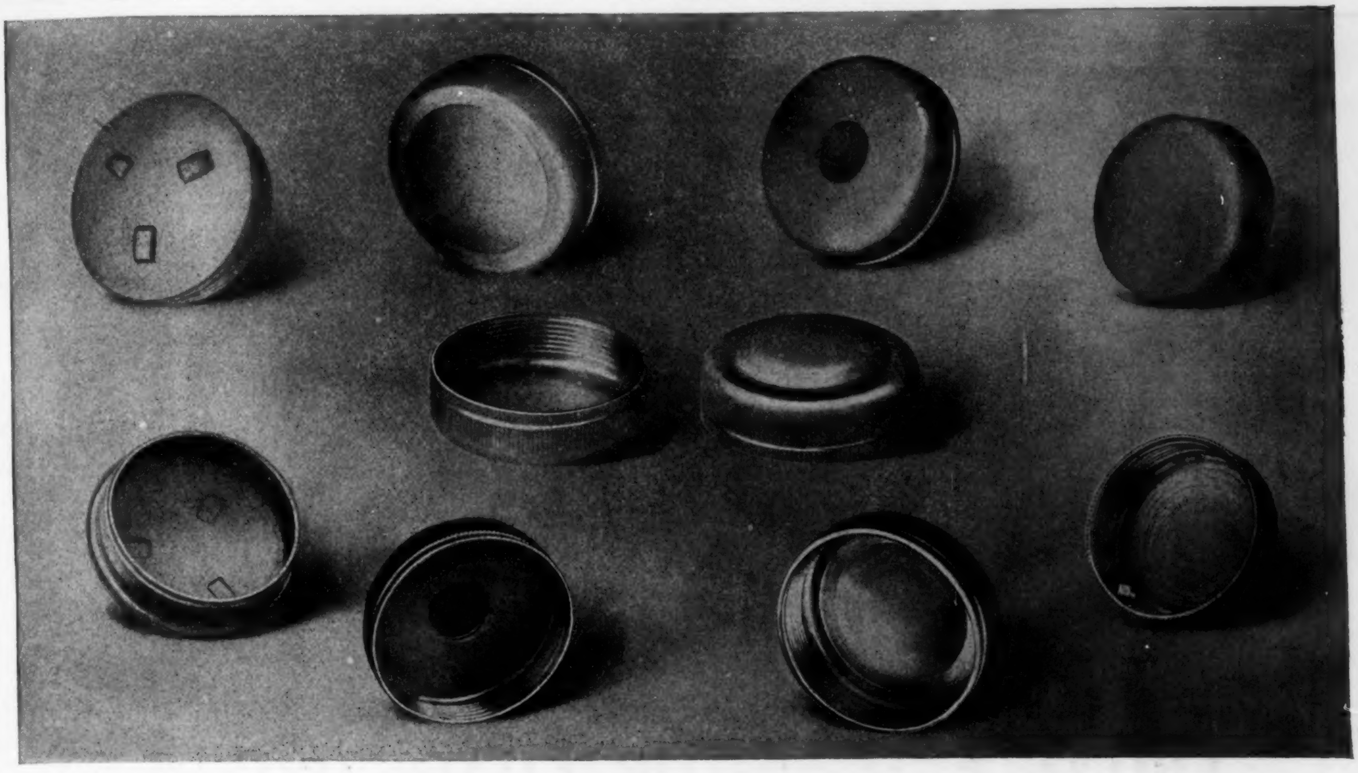


AGATHON
That
Crankshaft
Was Forged from Agathon Special Crankshaft Steel, Type No. 29A.
It was twisted into that fantastic shape as a test—while cold.
No sign of fracture or flaw.
Isn't that the kind of steel *you* want for this particular condition?
It's not a general purpose steel, nor do we advocate its use for other than shafting work.
For the special condition for which it has been developed, however, it is without qualification the most satisfactory steel obtainable.
Do you require the best form of alloy steel for *gear blanks? Connecting rods? Any other special purpose?*
There's an Agathon Steel Type expressly developed for *every individual condition* for which an alloy steel is demanded.
Agathon Formulas plus Agathon Quality equal Perfect Service.
Write us now respecting your immediate and future requirements.
THE CENTRAL STEEL COMPANY
MASSILLON, OHIO
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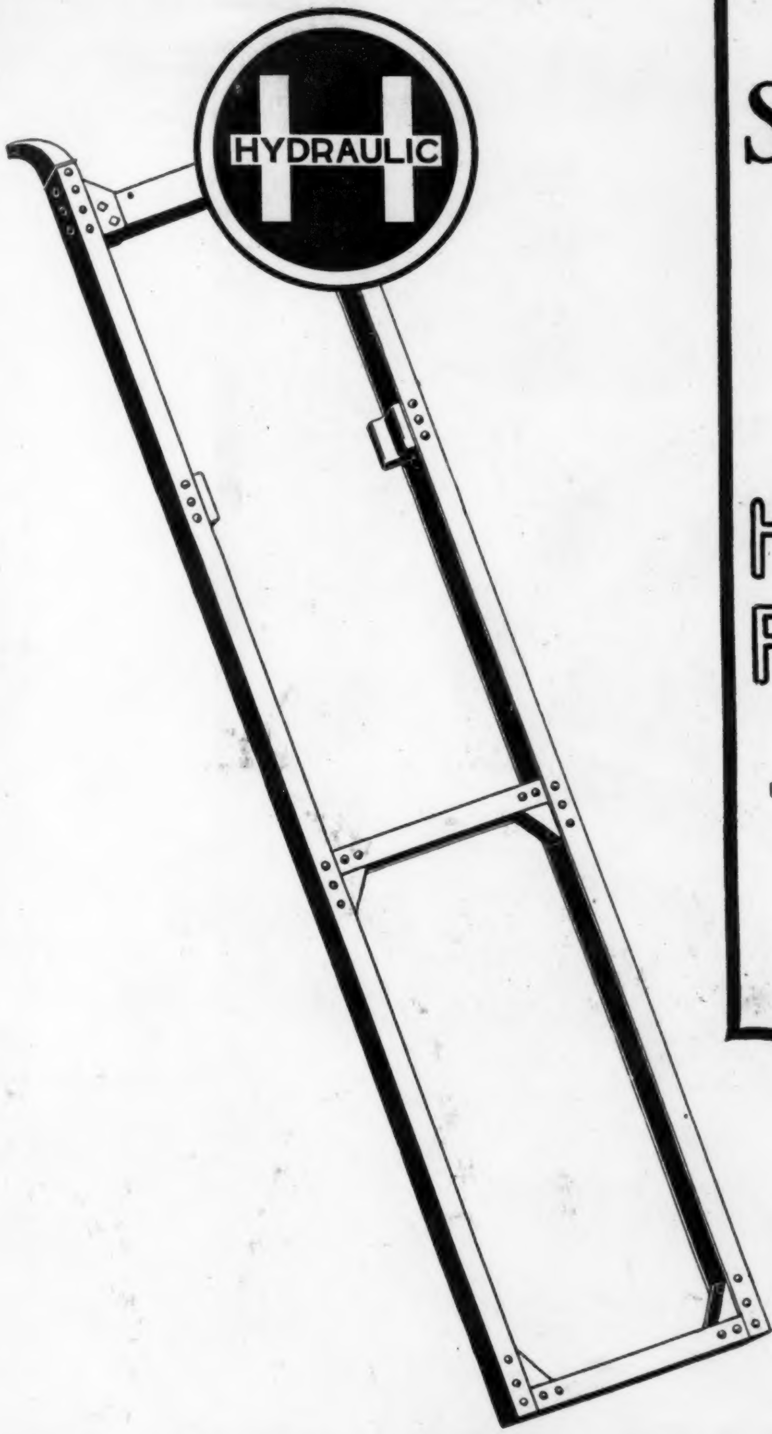
AGATHON STEELS


Ace
Ace


LOOK FOR THE BALL-POINT HAMMER MARKS INSIDE THE RING
American
Hammered
Piston Rings
PERFORMANCE
American Hammered Piston Rings are made to give service. Each month over one and three-quarters millions of concentric individual castings are machined and hammered into *leakless* piston rings.
The demand is for a leakless piston ring.
Ask Your Jobber
AMERICAN HAMMERED PISTON RING CO.
BALTIMORE, MARYLAND



Specifications

always mean more to the buyer when they include mention of

HYDRAULIC FRAMES

THE
HYDRAULIC PRESSED STEEL COMPANY
of THE HYDRAULIC STEEL COMPANY
CLEVELAND, OHIO

Branch Sales Offices:

New York
Singer Building

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Manufacturers of

Pressed Steel Frames for Passenger Cars, Trucks and Tractors; Axle Housings; Brake Drums; Torque Arms; Running Boards; Step Hangers; Hub Flanges; Discs; Dust Shields; Steel Barrels; Aeroplane and Miscellaneous Stampings.

HYDRAULIC PRESSED STEEL COMPANY

Positions & Men Available

The following announcements are published for the benefit of members of the Society and the convenience of companies in need of men. No charge whatever is made for this service. In the case of items prefixed by an asterisk further information is withheld at the request of the company or individual making the insertion, but written communications bearing the number of such items will be forwarded by the S. A. E. Office. In other cases further information will be supplied by the Office of the Society. Applications for positions from non-members must be endorsed by a member of the Society.

0904 YOUNG EXECUTIVE ENGINEER, with seven years' experience on tractors in field, also service, management, design, production and sales experience. Has held executive positions and now desires further sales and production work in the tractor or truck field.

0930 YOUNG GRADUATE ENGINEER with initiative and sales ability is seeking a sales engineering position. Four years of experience as a designer and sales engineer of heat-treating equipment and powerplant work and one and a half years' experience as a designer and sales engineer of truck axles. Excellent references.

0931 PRODUCTION MANAGER and mechanical engineer would consider a position requiring initiative and ability to handle production engineering problems successfully; twelve years' executive experience in automotive and allied industries; supporting testimony available.

0932 SUPERINTENDENT, practical mechanic, married, age 38, having thorough knowledge of production and cost and now engaged as maintenance superintendent. Is also experienced as production superintendent. Would prefer Pennsylvania as a location.

0933 DESIGNING ENGINEER on modern high efficiency engines. Has helped develop one of America's best four-cylinder cars in present connection. Many years of specialized experience in all problems of high-speed engine design, also laboratory and road testing experience. Seeks good opportunity as assistant chief engineer or head of engine design with progressive company.

0934 MOTOR-TRUCK FACTORY MANAGER and engineer desires new connection. Past locations few and of the best. Can maintain production at any desired pitch. Has thorough knowledge of the relation of the cost of manufacture and the quality of design to sales and finances. Best of references from present connection.

0935 WORKS MANAGER now employed by a leading Middle West corporation in the manufacture of high-grade passenger cars. Has also handled the quantity production of high-grade motor trucks. Thoroughly experienced in the organization of departments and thoroughly familiar with general labor conditions, having had supervision of all departments from the receipt of raw materials to the sale of finished product.

(Continued on page 52)

POSITIONS & MEN AVAILABLE *Cont.*

Men Available (Continued)

0936 DESIGNING ENGINEER AND DRAFTSMAN, with five years' experience on the design and construction of tractors, transmissions, kerosene and gasoline engines, desires to make a change. Capable of taking full charge of design, construction and experimental work.

0938 AUTOMOBILE ENGINEER Fifteen years' experience in automobile, aviation and marine work, specializing mainly on experimental and research work. Did the field work on the Cadillac for many years. Technical and practical. An able writer. A man of ideas and resource.

0939 PRODUCTION ENGINEER Technical graduate. Experienced in the design and production of piston-rings including both foundry and machine-shop practice and the design, construction and testing of gasoline engines, carbureters and other accessories as well as special production machinery, tools and fixtures. Location near Cleveland preferred.

0940 ENGINEER AND ORGANIZER, age 33, with considerable experience as machinist, tool maker and tool designer. Has been in charge of engine and chassis design, both for passenger cars and tractors, and is at present designing engineer on Government work. Speaks and writes German and is familiar with French and Italian. Wishes to hear from a progressive organization, either small or large, offering opportunities to a man with initiative.

0941 TECHNICAL AND PRACTICAL MAN with ten years' experience in charge of tractor field demonstrations and experiments and tractor and truck instruction schools. Has been tractor sales engineer and manager for four years and at present is sales manager for a truck distributor. Prefer to become associated with a large truck or tractor builder as sales manager, or in development and missionary work.

0942 MECHANICAL ENGINEER of executive ability, twenty-two years' experience covering design and development of methods, tools, machinery and equipment for economical production. Successful organizer experienced in factory management, maintenance and general construction, at present chief engineer and works manager, is open for engagement in similar capacity or as plant engineer.

0943 ENGINEER capable of taking entire charge of engineering department for the designing of internal-combustion engines, research testing, also the manufacture of engines. Past experience in this line has been with some of the very best engine builders, as assistant chief engineer, designing engineer, etc. Can give the best of references.

0944 ENGINEER Broadly experienced as an executive and designer on passenger cars and trucks, especially in applying anti-friction bearings, desires new connection.

0945 MECHANICAL ENGINEER Age 37. Experienced as chief engineer, production and sales engineer. Knows automotive and general mechanical construction and particularly familiar with pressed steel industry. Prefer sales work in Detroit, but will consider any proposition with a live company.

(Continued on page 54)

*See announcement at the head of the "Positions and Men Available" column, page 50.

POSITIONS & MEN AVAILABLE *Cont.*

Men Available (*Continued*)

0946 EXECUTIVE with twenty years' experience in manufacturing desires position. Formerly connected with largest ignition manufacturer as engineer and assistant works manager. Has successfully designed all types of ignition apparatus and is now chief engineer with firm in similar business. Can furnish best of references. Eastern location preferred. Married; age, 38. Interview solicited.

0947 AUTOMOBILE ENGINEER with executive ability backed by eighteen years' practical experience. Has good all-round knowledge of all branches of production and inspection, including foundry and forge work, metallurgy, design, manufacturing tolerances, screw threads, jigs and fixtures, machine-shop practice, assembling and testing.

0948 PRODUCTION ENGINEER Thorough mechanic and designer of tools, possessing the ability to produce. Has successfully held executive positions for the past ten years. Technically educated. Prefer position near New York City.

0949 FACTORY EXECUTIVE Age 32; Stevens graduate. Has worked up through the ranks, serving successively as machinist, foreman, designer, plant engineer, mechanical engineer and factory manager. Possesses broad experience in all phases of industrial engineering. Desires to affiliate with medium-size progressive company.

0950 DESIGNER AND LAYOUT DRAFTSMAN Technical graduate with five years' experience in design and layout of engines and transmissions desires a position with a well-established firm.

0951 SALES ENGINEER. Graduate mechanical and aeronautical with four years' successful experience in automotive parts and accessories work is anxious to connect with a progressive manufacturer. Has personally secured standard equipment contracts with a number of the largest automobile and engine builders. Experience includes engineering development, sales promotion and advertising. Moderate salary until ability is demonstrated. New York location preferred.

0952 ENGINEER to take charge of drafting room. Familiar with up-to-date drawing room practices, records and designs. Prefer motor-truck firm in Ohio or Michigan.

0953 EXECUTIVE with 12 years' engineering, sales service and production experience on passenger cars and trucks. Extensive outside practical experience and investigation has given knowledge of dealer and owner viewpoint and requirements. Possesses a wide acquaintance in the industry and a detailed knowledge of engines, axles and transmissions.

0954 ASSISTANT TRUCK ENGINEER. Graduate engineer with 15 years' design and three years' shop experience. Possesses original ideas, but is conservative and has had extensive experience in the design of tools and special equipment. Competent to take full charge of engineering. At present with large corporation.

0955 ENGINEER AND EXECUTIVE who has spent 17 years with some of the most prominent automobile builders in design, production and executive capacities, seeks new connection. Has designed and produced complete automobiles and trucks, including engines, transmissions and axles, and is interested in light-weight pas-

(*Continued on page* 56)

*See announcement at the head of the "Positions and Men Available" column, page 50.

POSITIONS & MEN AVAILABLE *Cont.*

Men Available (Continued)

senger car construction. Thoroughly conversant with latest production methods. Can furnish competent organization if desired.

0956 SALES AND DEVELOPMENT ENGINEER. Mechanical engineering graduate, experienced in research and steel production, is desirous of locating with live automotive company in selling end or sales development work. At present handling sales development work for prominent steel corporation. Wide acquaintance among tractor, truck and passenger-car engineers.

0958 CHIEF ENGINEER of tractor company who has demonstrated his ability to combine quality of product with low manufacturing cost desires position as chief engineer or manager of production with active firm.

0959 MECHANICAL DRAFTSMAN with five years' experience on passenger and truck layout and design, a technical education and shop experience desires connection with a company building trucks or passenger cars.

0960 YOUNG EXECUTIVE with nine years' practical and technical experience on passenger cars, trucks, tractors and aeroplanes. A live wire open for any of the following connections: research engineering, chief inspector or experimental supervisor.

0961 EXECUTIVE, 15 years' experience in automobile industry manufacturing and selling high-grade passenger cars. Qualified to act as assistant general manager, branch or export manager or in similar capacity. Energetic and enthusiastic worker, good organizer. Employed at present but available on short notice. Salary commensurate with results obtained. Age 35.

0962 SALES ENGINEER. Energetic young engineer with technical training and four years' automotive experience, including design, production, service and sales work. Desires further sales work with progressive automotive manufacturer.

0963 GRADUATE MECHANICAL ENGINEER with experience in engine and transmission development desires executive position in engineering or sales department. Age 25.

0965 CHIEF ENGINEER, age 38, desires similar or executive position. Eleven years' executive experience in the design and construction of heavy-duty internal-combustion engines, transmissions and tractors.

0966 ENGINEER, 15 years' experience, designer of one of the most popular four-cylinder cars, desires position.

0967 CHIEF ENGINEER with 16 years' technical and practical experience in engineering, production and executive work. Expert tool and die maker, practical designer and a successful executive.

0968 LAYOUT MAN AND DESIGNER, technical school graduate, long shop training, five years' experience in the design of motor trucks, lately engaged in the layout and design of pneumatic tire trucks of the multiple-wheel type.

(*Continued on page* 58)

*See announcement at the head of the "Positions and Men Available" column, page 50.

POSITIONS & MEN AVAILABLE *Cont.*

Men Available (Continued)

0969 PRODUCTION MANAGER AND ENGINEER, technical graduate, 15 years' practical experience in the automotive industry. Now chief engineer of a truck plant. Capable of designing a line of truck models and organizing for production. Available on a month's notice.

0970 SALES ENGINEER with 15 years' experience in the automotive industry desires to represent one or more products in New England on a commission basis.

0971 METALLURGICAL or SALES ENGINEER. Ten years' experience from ore to the finished products including foundries, forge shop, heat-treating plants and laboratory. Has specialized in automotive lines and built, installed and taken charge of laboratories and heat-treating plants for several well-known companies. Married; age 31.

0972 GENERAL MANAGER understanding machine assembling and design desires responsible position.

0973 PRODUCTION ENGINEER, works manager or general superintendent in an automobile or truck factory.

0974 ENGINEER, with experience on gas engines, heat-treatment of steel, production of tools, body making and efficiency work desires a position.

0975 MECHANICAL ENGINEER, age 35, experienced in the design and development of high-speed pneumatic-tired motor trucks, and as production manager of a motor-truck factory desires to make connection with a progressive motor-truck builder.

0976 CHIEF ENGINEER at present with company building trucks and passenger cars desires to make a change. Is a university graduate and has had 10 years' experience in automotive engineering and tool designing.

0977 AUTOMOTIVE ENGINEER, experienced in the design of a complete chassis, especially axles, springs, steering gear, etc., desires a position as chief engineer or assistant. At present assistant chief engineer of large parts manufacturer.

0978 FACTORY OR PRODUCTION MANAGER wishes to correspond with a company desiring a progressive and energetic executive, who is practical and uptodate and has increased production by the application of modern methods.

0979 PROGRESSIVE AUTOMOTIVE ENGINEER, a technical graduate, with 10 years' experience on automotive apparatus desires to connect with a company building internal-combustion engines. Is a resourceful designer of proven ability and competent to take charge of the design and construction of engines and allied products or direct experimental research laboratory.

0981 EXPERIENCED EXECUTIVE College graduate having legal and technical training coupled with practical experience and familiar with the automotive industry, desires change of position. Age 30. Eight years in present location.

0982 MECHANICAL ENGINEER with six years' experience in engine design and research work, two years as aviator in United States Air Service, desires a position, preferably testing or development work.

(Continued on page 60)

*See announcement at the head of the "Positions and Men Available" column, page 50.

POSITIONS & MEN AVAILABLE *Cont.*

Men Available (Concluded)

0983 Graduate Mechanical Engineer experienced before the war in research and experimental engineering, also testing and inspection with automobile and truck builders. Was Y. M. C. A. secretary during the war. Development work preferred. Age 25, married.

0984 Metallurgist with six years' experience in iron, steel and steel alloys and the metallurgical problems that arise in such work, in chemical analysis, physical testing, pyrometer work, metallographical examination and the handling of men engaged in heat-treating work.

0985 Executive Engineer, experienced in development and research work, maintenance and technical sales, desires position.

POSITIONS AVAILABLE

40 Electrical Engineer to teach automotive electricity in high-grade institute. Must have some practical experience and ability to teach. Location Chicago.

*62 Sales Manager with engineering experience for line which includes a patented part that is rapidly growing in favor. An opportunity on which to build a future for an energetic conscientious man.

66 Detailers desired for work on ordnance and tractor work. Location Illinois.

78 Mechanical Draftsman. A man having had some tractor experience will be given the preference. Location Nebraska.

81 Designers with experience on caterpillar type tractors. Location central New York.

83 Mechanical Engineer with metallurgical and heat-treating experience. College graduate preferred. Location Indiana.

*85 Experimental Engineer with wide practical experience to take charge of high-grade passenger car plant in western New York.

87 Designing Engineer experienced in automotive equipment, preferably gasoline and kerosene engines. Good opportunity for advancement in large progressive organization. Location Michigan.

88 Competent Engine Designers with experience on tanks, tractors and trailers. Location central New York.

89 Young Graduate Mechanical Engineer with some electrical knowledge to study working conditions in various plants of large manufacturing company. Position promises plant managership after business has been learned. Not allied with automotive industry. Location Ohio.

90 Superintendent with experience on grinding machines and in fitting up engines, or able to supervise work of that nature. Location Washington.

(Continued on page 62)

*See announcement at the head of the "Positions and Men Available" column, page 50.

POSITIONS & MEN AVAILABLE *Cont.*

Positions Available (Concluded)

91 SALES MANAGER Position open for young man with 8 or 10 years' experience with a new and progressive tractor company. Applicant must have tractor or truck sales experience. Exceptional opportunity for right man. Salary and commission. Interest may be secured in company later if mutually desirable. Location Middle West.

92 YOUNG ENGINEER who has specialized on internal-combustion engineering desired to assist in work involving compiling of statistical data and miscellaneous information on airplane engines. Sound knowledge of mathematics, mechanics and thermodynamics essential. Government position. Location Ohio.

93 RESEARCH ENGINEER who has specialized in field of oil engines and who has extensive knowledge of physics and electricity is wanted to direct a research program covering field of possible application of fuel injection internal-combustion engines to the propulsion of aircraft. Ability to invent new methods of measuring the desired quantities essential. Government position.

625 OHIO AUTOMOBILE MANUFACTURER has openings for **aggressive, well-educated young men capable of developing into executives and willing to start at modest salary. State age, height, weight, married or single, education, experience, knowledge of mechanical drafting and blueprint reading, service record, present salary, salary expected at start, whether any dependents, and if preference is for purchasing, sales, accounting, engineering or production.**

*See announcement at the head of the "Positions and Men Available" column, page 50.


Hartford
UNIVERSAL JOINTS
AND CONE CLUTCHES
The Joint of
Universal Satisfaction
The Hartford Automotive Parts Co.
Hartford Inc. 1906 Conn.

SOCIETY MEETINGS

Motor Boat Meeting and Dinner

New York City—Dec. 14th

At Automobile Club of America

Annual Meeting

New York City—Jan. 11-13

Carnival
Jan. 12

Annual Dinner
Jan. 13

Chicago Meeting

Feb. 2

Two Technical Sessions

Annual Dinner

Hotel Morrison

Columbus Tractor Meeting

Feb. 10

Two Technical Sessions

Tractor Dinner

Hotel Deshler

Place this in your follow up file

INDEX TO ADVERTISERS' PRODUCTS

The Index to Advertisers is given on pages 88 and 90

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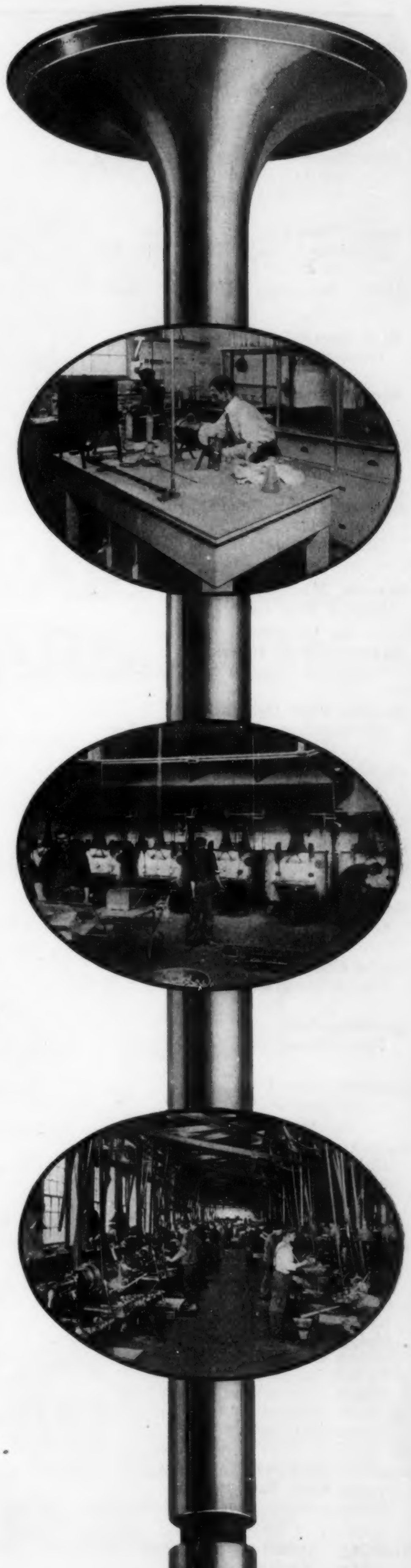

INDEX TO ADVERTISERS' PRODUCTS

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INDEX TO ADVERTISERS

The Index to Advertisers' Products is given on pages 80, 82, 84 and 86

COVERT TRANSMISSIONS

IN the modern, high-efficiency Motor Truck, operating often at High Speeds, friction reduction has become a matter of vital importance.

Covert Transmissions and Covert Clutches do not wastefully ***Absorb*** power; they faithfully ***Deliver*** it.

Because of this well-established fact, a standard, ball-bearing Covert Clutch and Transmission unit equipped the Duplex Limited Truck which recently traveled, with full load, 935 miles, in a continuous non-stop run of 24 hours.

Manufacturers of automotive vehicles to whom Quality and Performance are conscientiously paramount, specify Covert equipment.

They furnish it to you in their completed vehicles at a price no greater than that of other vehicles equipped with other clutches and transmissions.

See to it that the Truck, Passenger Car or Tractor you buy is Covert-equipped.

COVERT GEAR COMPANY, Inc.

Sales, Engineering and Factory: Lockport, N. Y.
Export Offices: 100 Broad Street, New York City

INDEX TO ADVERTISERS

The Index to Advertisers' Products is given on pages 80, 82, 84 and 86

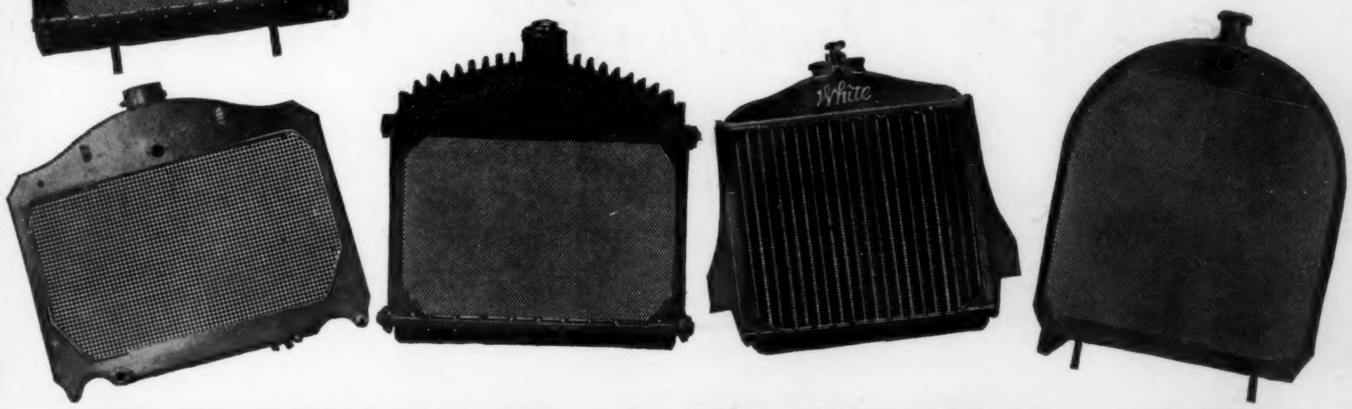
The Right Type for Each Service

Backed by an experience that dates from the industry's beginning, Fedders offers a choice of various radiator types to best meet the special cooling demands of each vehicle.

Big seven-ton trucks, light delivery cars, the highest priced limousines and the special-cooled runabout, all are proving in daily service that Fedders Radiators best solve their meter cooling problems.

"Ask Fedders"

Fedders
Manufacturing Co., Inc.
Buffalo, N. Y.



FEDDERS

TRUCK RADIATORS